3A 101A

Lubrication Fundamentals III: Friction Modifiers

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3811668: Friction Reduction Performance of Nanodiamonds in Presence of Organic Friction Modifier
Afrina Khan Piya, A. Al Sheikh Omar, Liuquan Yang, Ardian Morina, University of Leeds, Leeds, West Yorkshire, United Kingdom; Nazanin Emami, Luleå University of Technology, Luleå, Sweden

Using pin-on-disc tribometer at 50 °C and 80 °C, tribological performance of nanodiamonds(NDs) with Glycerol monooleate – GMO:organic friction modifier, Zinc dialkyldithiophosphate – ZDDP:anti-wear additive, and their combination was investigated with PAO: Polyalphaolefin synthetic oil. For binary additive system (except nanodiamonds), coefficient of friction represented similar values of individual additives. Surface adsorption of organic friction modifier, GMO over ZDDP and/or ZDDP breakdown products are responsible for observed tribological reaction. Nevertheless, nanolubricants showed remarkable synergistic effect on friction reduction at higher temperature through forming chemically reactive additive layers in which nanodiamonds were mechanically interlocked. Addition of 0.05wt% NDs to binary lubricating system, reduced COF approximately 60% at 80°C. Findings from the investigation of disc surfaces after tribological tests were substantiated by static SIMS, SEM, EDX, AFM and TEM.

8:30 - 9 am
3831281: Research on the Activation and Performance Retention of Organomolybdenum Additives
Brian Casey, David Boudreau, Vanderbilt Chemicals, LLC, Norwalk, CT

Organomolybdenum additives can provide significant friction reduction and wear protection to lubricating oils and greases through the formation of molybdenum disulfide (MoS_2). Whereas molybdenum dialkyldithiocarbamates (MoDTCs) and dialkyldithiophosphates (MoDTPs) can form MoS_2 directly, sulfur- and phosphorus-free molybdate ester (MoEster) additives must first sequester sulfur from other sources within a lubricant. The formulation style can affect both molybdenum activation to form MoS_2 as well as performance retention by maintaining the MoS_2 film. This presentation will focus on how various sulfur-containing additives can be used to influence the performance profiles of MoEsters in engine oils.

9 - 9:30 am
3834157: Effect of Organic Friction Modifiers on Friction and Wear of HDDEO Formulations.
Alexei Kurchan, Cargill Inc, Plainsboro, NJ

Drive for sustainability is strongly influencing lubricants technology. For new proposed diesel engine oil category (PC-12) Improvements requested include lower viscosity oils to support requirements for fuel economy for certain engine models, improved aftertreatment capability potentially lowering Sulfated Ash, Phosphorus, and Sulfur (SAPS) levels even further, and improved oxidation stability extended oil drain interval. With increased focus on fuel economy and wear organic friction modifiers will play an important role in lowering frictional losses and providing boost to wear performance. Use of traditional antiwear, extreme pressure additives, and inorganic Molybdenum-based friction modifiers increases total levels of SAPS and might not provide desired benefit for the duration of oil drain interval. We will present our work on efficiency of various organic friction modifiers in diesel oils based on tribological bench tests and aged oils performance in simulated oxidation.

9:30 - 10 am
3812392: Study of the Interaction Between Esters and Different Friction Modifier Additives in a Group IV Base Stock
Gerard Cañellas, Ariadna Emeric, Àngel Navarro, Lluís Beltran, Industrial Química Lasem, Castellgalí, Spain; Mar Combarros, IQL, Castellgalí, Barcelona, Spain; Montserrat Vilaseca, Eurecat, CTM, Manresa, Barcelona, Spain; Jordi Vives, UPC, Manresa, Barcelona, Spain

The replacement of conventional lubricants by esters is an alternative to improve formulations. Esters provide a low environmental impact and at the same time excellent lubricity features, high solubility of additives, good viscosity index, and high hydrolytic and thermal stability. Friction modifiers and extreme pressure additives are extensively used to save energy and increase operational life in machine components. In this study the lubricity of a Group IV base oil containing ester and various benchmark friction modifiers and/or extreme pressure additives is measured to evaluate the interactions between the mixture components. The tribological performance is discussed based on the tabulation of the friction coefficient using a MTM and on the measurement of the wear rate from wear scar of the experimental studies using an optical profilometer. In general, results show synergies between ester and additives reducing wear rate and friction coefficient.

10 - 10:30 am - **Break**

10:30 - 11 am
3813355: Bench Friction Evolution of Engine-Aged Oils
Brendan Miller, Ramoun Mourhatch, Chevron Oronite Company, Richmond, CA

Automotive fuel efficiency has been, and will continue to be, a key topic for OEMs and lubricant suppliers. As lubricant viscosities continue to drop for hydrodynamic gains in fuel economy, surface friction reduction will play a larger role in fuel economy performance. It is well known that current organic and organometallic FMs can provide fuel economy performance in fresh conditions, but their performance fades as the oils age in the engine. The authors show friction performance depletion over time for various organic friction modifiers aged in an engine.

11 - 11:30 am
3808868: Measuring the Frictional Behaviour of Lubricants with an Antiwear Additive and Different Friction Modifiers
Katherine Tomlinson, Tom Slatter, University of Sheffield, Sheffield, United Kingdom; Nick Morris, Paul King, Loughborough University, Leicestershire, United Kingdom

Frictional losses from the piston assembly in internal combustion engines is an area of interest for improving efficiency and reducing emissions. This study measured the frictional behaviour of lubricants with antiwear additives and different friction modifiers at a range of temperatures on a Nickel Silicon Carbide coated cylinder liner. A novel motored reciprocating tribometer isolated the friction at the interface between cylinder liner and oil control ring. Three lubricants were tested, all with the same 3% dispersant concentration and 1% ZDDP anti-wear additive, the first with no friction modifier, the second with inorganic friction modifier (molybdenum dithiocarbamates) and the third with organic friction modifier (amide). Results indicate that the organic friction modifier in combination with ZDDP does not reduce friction compared to the molybdenum dithiocarbamates, showing the importance of friction modifier selection with anti-wear additives on metal matrix composite coatings.

3B 101B

Rolling Element Bearings III

Session Chair: Alexander Fletcher, AFRL/RQTM, Wright Patterson Air Force Base, OH
Session Vice Chair: Daulton Isaac, AFRI Turbine Engine Division, Wright Patterson Air Force Base, OH

8 - 8:30 am
3833592: Influence of Residual Stresses Due to Cold Forming on Stainless Steel Bearings
Alexander Bodewig, Florian Pape, Gerhard Poll, Leibniz University Hannover, Garbsen, Lower Saxony, Germany

In this contribution, a simulative bearing fatigue life model based on Ioannides and Harris is transferred to stainless steel angular contact ball. Deformation-induced residual stresses are considered to model the strain hardening by cold forming of metastable austenitic steels due to compressive residual stresses due to the increase in volume of the martensitic phase, which has a positive effect on a components' fatigue life. In addition to rolling motion and sliding in the longitudinal direction, additional shear stresses induced

by the spin of the balls on the raceway are transmitted in angular contact ball bearings. Calculations with varied shear stress distributions are carried out for different bearing loads to quantify their influence on the bearing service life. The residual compressive stresses will be superimposed in the simulation. The calculations are validated with results from fatigue life tests.

8:30 - 9 am
3833799: Influence of High Loads on the Fatigue Life Behavior of Rolling Bearings
Simon Dechant, Institute for Machine Design and Tribology, Hanover, Germany

In practical applications, premature bearing failures may occur. One reason for this can be special events that cause high loads to occur for a short time. In order to investigate the influence of short-term high loads on the fatigue life of cylindrical roller bearings, experimental life tests were carried out. From single-stage tests with different load levels, an experimental Wöhler line can be determined as a reference value. In addition, two-stage tests were performed in which a high load phase was imposed at the beginning. Subsequently, the load was reduced to the base load level and the life test was operated until failure. The duration of the high load phase was varied in four different test series. The comparison of the one- and two-stage tests shows the influence of the high load phase on the fatigue life as a function of the high load duration.

9 - 9:30 am
3831513: An Investigation into Rolling Contact Fatigue Performance of Aerospace Bearing Materials
Steven Lorenz, Farshid Sadeghi, Purdue University, West Lafayette, IN

The objectives of this investigation were to experimentally and analytically evaluate aerospace-quality bearing steels in rolling contact fatigue (RCF). To achieve these objectives, 3 aerospace-quality bearing materials were manufactured into test coupons for torsional fatigue and rolling contact fatigue (3 ball-on-rod). First, 3 ball-on-rod tests were performed to qualify each material's RCF performance. Next, torsional fatigue experiments were conducted and the S-N data from these experiments was supplied to the developed analytical RCF finite element model to calibrate the damage rate equation, which considered the Fatemi-Socie as the failure criteria. The analytical model used continuum damage mechanics to simulate material degradation as a function of cycle. It was observed that good corroboration existed between the analytical simulation life predictions and the 3 ball-on-rod experimental results, with both sets of results establishing which material performed superior in RCF.

9:30 - 10 am
3813418: Predicting Surface Pitting Fatigue Behavior using Torsion Fatigue Characteristics
Kushagra Singh, Farshid Sadeghi, Purdue University, West Lafayette, IN

This work presents fundamental findings on equivalence of a surface pitting fatigue and torsion fatigue. A Thrust Bearing Surface Pitting Test Rig (TBSPR) was developed and utilized to conduct rolling contact fatigue experiments on case carburized gear steel. These tests were conducted at different contact pressure and fatigue cycles, followed by optical profilometry to determine the presence of surface pits. The results were used to develop the SN curve for surface pitting. Torsion fatigue experiments were conducted on the same material, and the SN curves of both modes of failure were compared. The results showed remarkable similarities between the shapes of these SN curves. This investigation shows that the surface pitting characteristics can be predicted by conducting much simpler, and faster, torsion fatigue tests.

10 - 10:30 am - **Break**

10:30 - 11 am
3834141: Effect of Surface Roughness & Lubrication Regime on Bearing RCF Life Using Computational Modeling Tool
Behrooz Jalalahmadi, Nick Weinzapfel, Sentient Science, Buffalo, NY

It is widely known that surface roughness of bearing races can significantly affect rolling contact fatigue (RCF) life. We utilize our DigitalClone for Engineering (DCE) bearing modeling tool to investigate the effect of surface roughness on lubrication regime, contact pressure profile and bearing RCF life. DCE is a physics-based RCF life prediction model which has been developed considering contact stresses, material microstructure, crack initiation mechanisms, damage mechanics, and probabilistic methods. To demonstrate the validation of DCE modeling tool, two different bearing types are studied under RCF

loading: a) off-the-shelf AISI 52100 cylindrical roller bearing (CRB), b) custom-made M50 angular contact ball bearing (ACBB). We perform both experimental RCF testing and computational RCF modeling using our DCE modeling tool. Due to variation of surface roughness of bearing races, two different lubrication regimes of mixed-EHL and boundary lubrication are created.

11 - 11:30 am
3812340: Wear Induced Changes in Surface Topography During Running-in of Rolling-sliding Contacts
Maruti Sai Dhiraj Sakhamuri, Terry Harvey, Robert Wood, University of Southampton, Southampton, United Kingdom; Bernd Vierneusel, Schaeffler Technologies AG & Co. KG, Schweinfurt, Germany

Running-in in rolling-sliding contacts under mixed-friction conditions involves asperity smoothing through mild wear and plastic deformation. To improve the prediction of service life or friction of bearings under mixed-friction conditions, knowledge of surface topography changes during running-in and their dependence on the operating condition is key. Therefore, this study investigates one of the operating variables, slip. AISI 52100 steel specimens were tested in a PAO base oil at various slide-roll ratios in a mini traction machine operating under the mixed lubrication regime. A novel method of pre and post-test surface relocation with 3-D optical profilometry and SEM was implemented. The near surface region was investigated using FIB. The results exhibit the rapid nature of running-in. Asperity removal and excessive plastic deformation due to slip are shown at high magnification. FIB analysis links this plastic deformation in the running-in stage to non-ideal bearing performance.

11:30 am - 12 pm
3812773: Investigation on Strength of Steel and Silicon Nitride Rollers Against Fracture
Nikhil Londhe, Aaron Muhlenkamp, Hiroshi Marunaka, Timken Company, North Canton, OH

Recent demands for optimized mechanical power transmissions have led to use of smaller size bearings operating under higher contact loads. For successful performance it is necessary to develop stress guidelines for rolling bearings to prevent roller fractures and crushing under high contact loads. This study presents experimental and numerical investigation of strength of steel and silicon nitride cylindrical rollers against fracture and ultimate crushing. Steel rollers were manufactured using different heat treatments and silicon nitride rollers were hot pressed. Because of high hardness of silicon nitride, experiments were carried out with special tooling. Profiles were designed on the parts to concentrate stresses in specific regions, and which become crack initiation sites. Contact stresses were estimated using numerical simulations. Experimental results show good agreement between strength and fracture properties of steel rollers manufactured using different heat treatments.

3C 102A

Fluid Film Bearing I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3804785: An Optimized Normalization of the Inlet Computation Zone for Isothermal EHL Contacts
Yuko Higashitani, Sanemasa Kawabata, DENSO CORPORATION, Showa-cho, Kariya-shi, Japan; Marcus Björling, Andreas Almqvist, Luleå University of Technology, Luleå, Sweden

Lubricated contacts in cam mechanisms, rolling bearings, etc. typically operate under elastohydrodynamic lubrication (EHL). The useful life is closely related to the oil film thickness, suggesting that the possibility of predicting it is an important facility when developing machine elements including EHL contacts. Most of the numerical calculation methods for EHL film thickness, employ a fixed multiple of the Hertzian radius for the normalization of the computational domain. However, the solutions obtained might be numerically starved, especially under low-load, high-speed conditions. The present fully-coupled FEM-based model, incorporates an optimized normalization of the inlet length, ensuring appropriate meshing over a wide range of operating conditions, efficiently avoiding numerical starvation. The present method can, therefore, be used to obtain accurate EHL solutions over a wide range, including the

transition regions between high-load and low-load, high-speed and low-speed.

8:30 - 9 am
3811673: Experimental Investigation on Thrust Bearing Cooling Arrangement Within Tilting Pads.
Farooq Najar, G A Harmain, NIT Srinagar, Srinagar, J&K, India

The present paper describes the influence of cooling circuitry within the thrust element (tilting pads) in a thrust bearing. The experimental set up was Indegionously designed with various types of cooling circuits. One of the circuits designated as circuit-II has been installed in the set up and tests were carried out. During testing, the inlet temperature of lubricant (SAE 30) was maintained at 40 ^{o}C, the load and whirl combination was set at 5 kN and 1400 rpm respectively. The results has shown a significant drop in the oil film temperature which in turn helps the thrust bearing set up to withstand for utmost load condition.

9 - 9:30 am
3804389: Static and Dynamic Behaviour of a Porous Bearing Lubricated by Nanofluids
Benyebka Bou-Saïd, INSA Lyon, Villeurbanne , France

We present a numerical simulation model of porous journal bearings considering the fluid film – poroelastic matrix interaction and the non-Newtonian rheological behavior of nano lubricant consisting of base fluid and nanoparticles (NPs). The flow of the nano lubricant in the porous medium is modeled by the modified Darcy's law where the Beavers–Joseph slip condition is applied at the fluid film-porous matrix interface.The hydrodynamic pressure induced deformation of the fluid film- porous matrix interface is calculated by using a simplified analytical model «Thin Elastic Liner Model". The bearing porosity is introduced into the Reynolds equation by means of the Morgan-Cameron approximation. .

9:30 - 10 am
3811830: Dynamic Analysis of Finite Porous Journal Bearing considering Cavitation
Elizabeth Clifford, The University of Akron, Akron, OH

A novel approach to modeling multiphase fluid film within a porous journal bearing was presented. Pseudo cavitation contributed a gas phase to the liquid within the bearing. The physics-based approach conserved mass while solving the coupled Rayleigh-Plesset (RP) and Reynolds (RE) equations to produce the time-dependent void fraction of the fluid film. The void fraction was used to update density and viscosity properties of each fluid grid cell. The three-dimensional pressure distribution dictated the injection velocity from the porous bushing. The work presented a novel analytic solution for pressure distribution in the porous medium which coupled to the RP-RE equations. Effects of cavitation on the fluid film on pressure distribution and bearing stability were investigated. Select cases were compared with previous work for approach validation.

10 - 10:30 am - **Break**

10:30 - 11 am
3811880: Thin Film Momentum and Energy “Bulk Flow” Equations With Velocity and Temperature Profiles
Mihai Arghir, Universite de Poitiers, Futuroscope Chasseneuil, France

The momentum “bulk flow” equations are a mathematical model for the thin film flow with large reduced Reynolds numbers when convective inertia forces are important. The original equations were deduced by considering that the inertia forces do not modify the parabolic velocity profile that prevails in low to moderate Reynolds number laminar flows. The present work uses a fourth order polynomial for describing the velocity profile in the thin film flow dominated by convective inertia. The five coefficients of the velocity profile are expressed by using the average velocity and by imposing the no-slip boundary conditions and the wall shear stresses. A similar approach is adopted for the temperature profile needed in the energy “bulk flow” equation and is coupled with the momentum “bulk flow” equations. The new equations are solved for a slider operating at high reduced Reynolds number and the results are compared with the solution of the classical Reynods, “bulk flow” and energy equations.

11 - 11:30 am
3834094: A Directed-Lubrication Thrust Bearing Solution for High-Speed and/or High-Load Applications
Bruce Fabijonas, Richard Rodzwic, Kingsbury, Inc., Philadelphia, PA

We present recent results of the performance of a directed-lubrication thrust bearing being investigated at Kingsbury, Inc. The design has been effective in cooling thrust bearings at high speeds and high loads on the test rig. Unlike other directed-lubrication bearings, the design goal is to allow for oil flow rates greater than those typical of a directed-lubrication bearing with a focus on cooling the bearing and meeting the customer's operating conditions. We compare the performance results on the test rig against a flooded design and another directed-lubrication design. Finally, we discuss the results of CFD simulations of the bearings in an effort to understand the behavior of heat dissipation within each bearing type.

3D 102B

Materials Tribology III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3834326: Dry Sliding Wear of Metal-oxide Filled PTFE Composites
Jackson Swets, Joseph Berbach, Harman Khare, Gonzaga University, Spokane, WA

The addition of nanoscale alpha-alumina to polytetrafluoroethylene (PTFE) reduces wear of PTFE by nearly four orders of magnitude under dry sliding on steel. Ultra-low wear of alumina-PTFE composites is enabled by growth of robust tribofilms on both the composite pin and steel surface. Tribofilms are developed in part through friction and shear stress as a result of sliding with the availability of ambient humidity. PTFE composites reinforced with certain other metal oxide nanoparticles result in wear rates comparable to alumina, while others result in significantly higher wear for reasons that remain unclear. Brass countersurfaces are similarly known to result in higher wear, irrespective of filler choice, including alumina. In the current work, morphological and chemical analyses of worn interfaces are used to determine factors – particularly related to chemical interactions in the interphase region and on the counterface that help promote low wear of metal-oxide PTFE composites.

8:30 - 9 am
3835100: Qualitative Analysis of Transfer Film Properties on Wear Performance of Metal Filled Fluoropolymer Composites
Faysal Haque, Mark Sidebottom, Miami University, Oxford, OH

Unfilled Polytetrafluoroethylene (PTFE) has a low friction coefficient, but also a high wear rate ($K \sim 10^{-4}$ to 10^{-3} mm^3 /Nm). Over the years, PTFE has been composited with different materials such as α-Al_2O_3, GeO_2, BeO, activated carbon nano fillers etc. to reduce the wear rate by ~10^4 against 304 SS. These are known as ultra-low wear materials. Recently three metal fillers (Cr, Ti, Mn) particles were able to achieve ultra-low wear rate in Brass 260 but mixed performance against 304 SS. This discovery of new fillers and counterbody motivated to explore other countebodies such as Cu 110, Zn galvanized steel to find the relationship between wear rate and counterbody hardness. This will help us to understand how a hard particle like Cr was able to form stable transfer film on Brass 260 but did not perform well against 304 SS. For this presentation, the PTFE-Cr is tested with different counterbodies and the quality of the transfer film was analyzed.

9 - 9:30 am – Presentation TBD
Mark Sidebottom, Miami University, Oxford, OH

9:30 - 10 am – Presentation TBD
David Burris, University of Delaware, Newark, DE

10 - 10:30 am - **Break**

10:30 - 11 am
3834303: On the Dry Sliding Wear of PEEK-PTFE Composites
Elizabeth Anders, Harman Khare, Gonzaga University, Spokane, WA

The addition of nanoscale metal-oxide fillers to polytetrafluoroethylene (PTFE) has been shown to be

highly effective in reducing wear of unfilled PTFE. Despite their ability to reduce wear of PTFE by almost four orders of magnitude, an increase in wear is observed, for instance, when composites are run at high temperatures, in the absence of ambient humidity, etc. In contrast, polyether ether ketone (PEEK) is recognized as a more robust filler for PTFE in terms of achieving wear rates which are lower by over four orders of magnitude compared to unfilled PTFE, under a wider range of conditions. This work reports on the results of dry sliding wear with PEEK-PTFE composites under conditions which are otherwise known to disrupt low wear of PTFE composites filled with metal-oxide fillers. Results from tribological, chemical and morphological characterization of PEEK-PTFE sliding interfaces are presented, giving insight into the mechanochemical mechanisms driving variations in wear rates.

11 - 11:30 am
3834238: Tribological Behavior of PTFE-PEEK: Influence of Composite Processing
Kylie Van Meter, Brandon Krick, Florida State University, Tallahassee, FL; Christopher Junk, CJIdeas LLC, Wilmington, DE

Polytetrafluoroethylene (PTFE) is widely used in tribology applications as a solid lubricant; it is thermally stable, chemically inert, and has very a low surface energy and coefficient of friction (<0.1), but suffers from a high wear rate. PTFE filled with poly ether ether ketone (PEEK), a high performance thermoplastic, has been shown to achieve ultralow wear rates ($K< 10^{-7}$ mm^3/Nm) and low friction (<0.2). PTFE-PEEK composites can exhibit inconsistent tribological behavior from sample to sample, with wear rates of compositionally identical samples varying by multiple orders of magnitude. In this work, these variations are found to be influenced by processing conditions such as composite mixing and sintering conditions. Tribological and mechanical characterization of composites fabricated with varying processing conditions, along with chemical analysis of the sliding interface, is used to elucidate the impact of composite processing on the tribological behavior of PTFE-PEEK.

11:30 am - 12 pm
3830056: Design of PEEK-based Composites for Multifunctional Applications
Surojit Gupta, Shawn Ruggiero, Caleb Matzke, University of North Dakota, Grand Forks, ND; Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Polyether ether ketone (PEEK) is an important polymer thermoplastic material which can be used in different demanding applications. Brittleness and poor tribological behavior are some of the issues with PEEK-based compositions. In this study, different additives like MAX and MAB phases will be explored to enhance the mechanical and tribological properties. We will present detailed microstructural characterization of these composites. The mechanical behavior of these composites will be also presented. In addition, tribological behavior of these composites in dry and lubricated conditions will be presented by ball-on-disc method. Detailed analysis of wear tracks after tribological measurements will be presented. Finally, these results will be compared with different PEEK-based composites.

3E — 102C

Condition Monitoring III

Session Chair: Greg Horwich, Gastops, Dartmouth, Nova Scotia, Canada
Session Vice Chair: TBD

8 - 8:30 am
3816883: Wear Metal Alarm Limits Versus Trending
Evan Zabawski, Eurofins TestOil, Strongsville, OH

Oil analysis users commonly ask, "How much wear is normal/abnormal?", and they tend to get a range of answers from generic to misleading. This presentation will begin by clarifying why that question poses such difficulties in getting a straight answer using clear examples applicable to any type of asset. Variables such as viscosity, sump volume and oil service all play a vital role in establishing reasonable limits, which is why there is no one set of published limits. Even attempts at using rate-of-change are fraught with inaccurate assumptions that mask real issues. This presentation will conclude by showing how trending avoids all the common pitfalls of the other methods.

8:30 - 9 am
3831987: Rapid Identification and Quantification of Ethylene and Propylene Glycol in Engine Coolant by Gas Chromatography.
Nicholas Lancaster, Cory Schomburg, Lee Marotta, Leeman Bennington, PerkinElmer, Waltham, MA

Determining the glycol type and concentration of an engine coolant is a useful analytical test for in-service testing laboratories to both identify the coolant type and determine whether the coolant is fit for its intended purpose. Standard specifications for engine coolants prescribe that a glycol concentration between 40 - 60 %v/v in water of suitable quality, will function effectively during winter and summer. As such repeat testing to asses the glycol content over the lifespan of the coolant is required to avoid problems. Commonly, glycol content is determined manually using a refractomer, either in the field or in the laboratory. Gas Chromatography is an alternative analysis technique for glycols that allows for automation of large batches of coolant samples and can identify the glycol present in the coolant in addition to determining its concentration. With correct optimization, analysis time can be kept as low as five minutes per sample with minimal sample preparation.

9 - 9:30 am
3832529: Filter Element Construction and Electrostatic Discharge Polarity in Hydraulic Systems
John Duchowski, Hydac FluidCareCenter GmbH, Sulzbach, Saar, Germany; Keith Windebank, Tobias Daley, Hydac Technology Ltd., Witney, Oxfordshire, United Kingdom

The electrostatic discharge (ESD) phenomena in hydraulic and lubricating systems are well understood. ESD arises as a result of energy difference between the glass fiber filter material and the hydrocarbon fluids employed in these systems. Charges separate as a result of these energy differences, no friction is required. This energy difference is on the order of 30 Jm^{-2}. The glass fiber at far left end of the triboelectric series acts as an electron donor and the hydrocarbons towards the middle as an acceptor. In most applications a negative charge is measured in the fluid. At the 2018 Meeting we reported polarity reversal as a result of different oil formulations. The case involved an oil blend with a large content of naphthenic stock with specialized additives for low temperature applications. We now report polarity reversal as a result of differences in filter element construction. The events were observed on hydraulic mules employed for supplying power to aircraft on the ground.

9:30 - 10 am
3833748: An Automated Approach to Gravimetric Dilution for Lubricant ICP Sample Preparation and Analysis
Steven Twining, Elemental Scientific, Inc., Navasota, TX

Inductively Coupled Plasma gravimetric sample preparation often requires the most skilled analysts performing high precision dilutions by weight, often in a hood, for hours on a daily basis. A new automated technology has been developed that dilutes samples accurately and precisely. This highly flexible system prepares a variety of samples over a wide viscosity range. Combined with a second technology that incorporates non-mechanical gas infusion homogenization, automated lubricant gravimetric sample preparation is now possible.

10 - 10:30 am - **Break**

10:30 - 11 am
3833834: Asset Condition Assessment, Field Application
Marc Yarlott, Veolia North America, Vancouver, WA

Understanding an asset’s life cycle status is essential for asset management because decisions about system capacity, asset repair/replacement, and priorities can all be established with accurate asset life cycle status ranking. Asset life cycle status is directly driven by the asset condition and the methods used to establish the condition assessment. This case study will examine asset condition assessment field gathering methodes and data collection in a computerized maintenance management system (CMMS), including mobile data collection tools. Learning objectives include: 1.) Field measurement methods, 2.) Developing a repeatable condition assessment rating criteria for a complex asset and 3.) Workflow for collecting, analyzing, and updating the condition scoring in CMMS (Infor EAM Example).

11 - 11:30 am
3812939: Real-time Online Determination of Lubricant Remaining Useful Lifetime and Detection of Common Lubrication Contamination Events
Timothy Mack, Greg Horwich, Gastops, Dartmouth, Nova Scotia, Canada

The extent to which online lubricant condition monitoring and real-time predictive maintenance will be adopted is contingent on the development of on-equipment sensors that are rugged, cost-effective, and miniature and analyte specific. It will also be desirable that the underlying physics of sensor operation should be sufficiently well-understood to properly harness statistical data analytics tools and scrutinize their predictions. This paper presents examples of suitable sensor technologies that can address the criteria above. Such sensors can be employed both to identify specific common lubricant contamination events, such as coolant or fuel contamination, as well as provide a real-time estimate of lubricant remaining useful lifetime based on in-situ detection of antioxidant degradation species. By combining data from complementary sensors, improved prognostic maintenance models can be developed, leading to equipment reliability improvements as well as maintenance cost reductions.

11:30 am - 12 pm
3831245: The Impact of Oil Additive Types and Their Content on the Oil Electrical Conductivity.
John Duchowski, Andrei Wenzel, Hydac FluidCareCenter GmbH, Sulzbach, Saar, Germany

An investigation to determine the impact of oil additive types and their content on the oil electrical conductivity has been carried out for several additive types blended into the oils of different API Groups at different concentrations. The investigation was carried out systematically and in a step-wise fashion. Representatives from all the four hydrocarbon based API oil groups were selected as were representative additive types. The latter included antiwear/extreme pressure, antioxidant and viscosity index improver. In order to delineate the impact of each, the additives were blended in individually and in regularly increasing concentrations levels that are typically employed in standard formulations. The results were quite surprising and will be described in detail in the course of the technical session.

3F 103A

Environmentally Friendly Fluids II

Session Chair: Brajendra Sharma, USDA/ARS/NEA/ERRC, Wyndmoor, PA
Session Vice Chair: Daniel Garbark, Battelle Memorial Institute, Columbus, OH

Session Starts at 8:30 am

8:30 - 9 am
3811270: Viscosity Modifiers With an Environmental Acceptable Design and an Improved Performance
Mar Combarros, Marc Alumà, Taro Ehara, IQL, Castellgalí, Barcelona, Spain; Ariadna Emeric, Gerard Cañellas, Àngel Navarro, Industrial Química Lasem, Castellgalí, Spain

New environmentally acceptable viscosity modifiers have been developed as an alternative and improving performance of common additives in the market. These specifically designed organic polymeric structures show good thickness efficiency, offer good lubricity, volatility, and especially good shear stability. We have tested shear stability using the KRL tapered roller bearing shear stability test, evaluating the change in viscosity and the molecular breakage. A higher shear stability compared to other products in the market and a dependence on the size of the molecule was found. Lubricity was tested using SRV and MTM obtaining a reduction in coefficient of friction. Furthermore, when the new viscosity modifiers are used, much lower volatilities are observed by thermogravimetric analysis in the formulations. Finally, compatibility with other common viscosity modifiers and additives was investigated.

9 - 9:30 am
3811333: Degradation and Lubrication of Stern Tube Seals- Understanding Seal Durability
Tom Briggs, Philippa Cann, Marc Masen, Imperial College London, Oxford, United Kingdom

The stern-tube seal is the ship component responsible for retaining the stern-tube bearing lubricant and excluding seawater. The introduction of environmentally acceptable lubricants has created new challenges for seal manufacturers- namely a significant drop in reliability due to surface damage at the shaft-seal interface. Little research has been carried out on seals that operate in seawater-oil, although there is significant work into air-oil seals. The project is an experimental study of stern-tube seal degradation operating in a seawater-oil environment. Results from a novel bench test, simulating the seal operation, will be presented. The test uses a glass ring as the shaft element which allows the use of techniques to measure film thickness, initiation of surface damage and composition of the interfacial film using in-situ techniques. Post-test analysis of aged seals is also possible using SEM and nano-indentation. Full-scale tests will also be presented for validation purposes.

9:30 - 10 am
3830387: Achieving Performance and Sustainability Objectives with Ester Technologies
Matthias Hof, Emery Oleochemiclas GmbH, Duesseldorf, NRW, Germany

Over the last years, sustainability has increased in importance in our industry. Stakeholders in our industry along the value chain continue to recognize and adopt the practice of being more sustainable and transparent about use of raw materials, CO_2 emissions, waste management and recycling potentials. This paper will highlight how finding the balance to achieve both performance and sustainability objectives in modern applications can be addressed by implementing proven as well as new ester technologies and strategies. The usage of existing renewable, bio-based but also petrochemical raw materials will play a major part in this development. Due to the highly flexible chemistry design of ester components and base stocks, this technology can play an important role in helping the formulating industry to reach their sustainability goals for all types of lubricant applications. Technical performance benefits along with more environmentally-friendly properties will be discussed.

10 - 10:30 am - Break

10:30 - 11 am
3804219: An Environmentally-Responsible Approach to Improving Your Heat Transfer Fluid Chemical Hygiene
Richard Beemsterboer, ORG CHEM Group LLC, Oak Lawn, IL

Thirty years ago, Heat Transfer Fluid (HTFs) manufacturers would encourage and provide full-system replacement of used HTFs with virgin fluid and dispose of the used HTFs without regard for the potential of remediating the used fluid. Times have changed. HTF users needed an alternative to dump and dispose of the used HTF by burning or landfilling and replacing it with virgin products. Processing a synthetic, high-temperature heat transfer fluid allows the user to have the foulants of the liquid removed or 'reclaim' the 'good' distillate, and enhance the chemical sustainability of their organization by re-using a chemical in place of disposal. Reclaiming and recycling a heat transfer fluid for continued use is an economical, ecological and responsible approach to specialty chemical management. This talk presents an alternative to disposing of and replacing an HTF with a more environmentally-friendly way to extend the life of an HTF and meet Sustainability and ESG initiatives.

11 - 11:30 am
3831292: A New Safer and Sustainable Turbine Oil
Gregoire Herve, NYCO, PARIS Cedex 08, France

Modern lubricants in particular state-of-the-art technologies need to reach performance. Sustainability is an additional requirement that becomes more and more important. Final users ideally desire non-hazardous materials with complete absence of safety & health risks combined with minimum impacts on the environment.
Such a complete package becomes a challenging goal for industrial companies. Aviation turbine oils have been used since Second World War II. Despite Technology & Science evolution, those lubricants are still a major concern as they still contain toxic components such as antiwears and antioxidants. Here is presented an original toxicity cross-evaluation combining modeling and experimental studies applied on the toxic substances leading to a safe and risks-free formulation. Lastly, thermal and tribological evaluations highlight a similar level of high performance compared to existing oils. No trading-off was done implying that sustainability and performance can truly co-exist.

Gears I

Session Chair: Chengjiao Yu, Hebei University of Technology, Tianjin, China
Session Vice Chair: Pinzhi Liu, ExxonMobil Research and Engineering, Annandale, NJ

8 - 8:30 am
3810701: Pitting Detection in an Early Damage Stage for AI Based Operating Strategies in Wind Power Drives
Lukas Merkle, Martin Dazer, Andreas Nicola, University of Stuttgart, Stuttgart, Germany

Gear failure caused by pitting is one of the leading reasons of downtime in wind turbines. An adaptive operating strategy applies a load reduction of a damaged tooth by the means of torque variation to increase the remaining useful life. For the highest possible increase of service life, a detection of pitting damage at an early stage during operation is necessary. To investigate the detection possibilities on the test rig, a test gearbox is developed. The tooth flanks of test gears are manufactured with artificial pitting damage at different stages. The test gearbox is equipped with various load and vibration sensors mounted at different positions of the housing. The sensors acquire a large amount of data, depending on the size of the damage. The test results are used to train deep neural networks for AI based plant operation. The experiments not only show at which stage pitting damage is detectable, but also form the data basis for AI based condition monitoring of wind power drives.

8:30 - 9 am
3811272: Formulating for an Increasingly Complex Industrial Gear Landscape
Paul Norris, Helen Ryan, Afton Chemical Ltd, UK, Bracknell, United Kingdom

Premium Industrial Gear products are now expected to meet an increasingly complex and demanding set of OEM and Industry specifications. These diverse specifications reflect a huge variety of end uses, ranging from small material handling systems to heavy duty industrial operations, that need to be considered and catered for in any new development, pushing the boundaries yet further. In addition, customer base oil requirements are also evolving, and these also need to be factored into any fit-for-purpose testing program. Many of the required Industrial Gear oil performance attributes have competing needs and thus the target area for a successful formulation is continually reducing in size. A selection of the key challenges, and approaches taken to address them, will be discussed.

9 - 9:30 am
3811282: Investigations on the Pitting Resistance and Efficiency of Gears With Very Smooth Surfaces
Adrian Sorg, Thomas Tobie, Karsten Stahl, Technical University Munich, Garching b. München, Germany; Dominik Kratzer, Klueber Lubrication Muenchen GmbH & Co. KG, Munich, Germany

The flank load carrying capacity and efficiency of gears depend strongly on the lubrication conditions in the contact zone of the meshing gears. In this publication, extensive investigations were carried out on case-hardened gears from different grinding processes resulting in low surface roughness and thus beneficial operating conditions. Experimental tests in the FZG standard back-to-back test rig using an ISO VG 100 lubricant with those gears show that fine tooth flank surfaces increase the pitting load carrying capacity. Random sample tests with lubricants from practical application indicate the transferability of the results to practical conditions. Recommendations are developed to allow an optimization of existing load carrying capacity calculations within ISO 6336. Furthermore, efficiency tests at different operating conditions not only show the influence of surface roughness but also of the grinding process itself.

9:30 - 10 am
3812296: Method for Characterization of Wear Behavior of Steel-bronze Rolling-sliding Contacts Relating to Worm Gears
Philipp Schnetzer, Technical University of Munich, Garching bei München, Germany

Worm gears are usually used in industrial applications with the material pairing of hard worm and softer worm wheel, where the failure type wear often limits the service life. Up to now, extensive, costly and time-consuming component wear tests need to be carried out for each tribological pairing in order to

predict the amount of wear on worm gears. For this reason, this presentation covers a new method to characterize the wear behavior of steel-bronze rolling-sliding contacts regarding worm gears. Therefore, tribological conditions for a model contact tested on a two-disk test rig derived from a worm gear tooth contact will be presented. Based on this, a method for gravimetric wear determination will be explained. Further, the wear behavior for a steel-bronze pairing will be characterized on the model contact. Special focus is given to similar trends in wear behavior observed between worm gear and two-disk tests and this with significantly shorter test run times of the new method.

10 - 10:30 am - **Break**

10:30 - 11 am
3810716: AI Based Prognostic and Health Management in Wind Power Drives
Lisa Binanzer, Martin Dazer, Andreas Nicola, University of Stuttgart, Stuttgart, Germany

Gear failure caused by pitting is one of the leading reasons of downtime in wind turbines. An adaptive operating strategy applies a load reduction of a damaged tooth by the means of torque variation to increase the remaining useful life. For the highest possible increase of service life, condition monitoring data is used to implement an AI-based prognostic and health management strategy. Measurement data from several gears with different degrees of pitting are recorded with a test gearbox. The labeled data are used to train intelligent neural networks for automatic pitting detection during operation. By using reinforcement learning and artificial intelligence it is possible to identify the degree of pitting and the time of occurrence. Different approaches and methods are investigated. Based on this, an intelligent control can be implemented. In summary, the integration of AI in the control of wind power drives enables the increase of the remaining useful life.

11 - 11:30 am
3815106: Catastrophic Failure of Gears in a Tube Mill
Arturo Cardenas, GIGATEC, San Luis Potosi, SLP, Mexico

Gears have played a vital role in the industry since the very beginning. And nowadays, a failure can mean significant disruption to the production lines. Gears are almost always subjected to very high overloads and pressures, making precision and lubrication key factors in preserving reliability. Also, in some cases, gears work under large amounts of metal-forming coolant, which means water contamination. In the same way, bearings are under the same conditions as gears, and both suffer from the effects of the EHL friction losses in the line of contact. In this case, we have a 300 HP tube mill with a catastrophic failure just one month after the user decided to switch to the oil supplier. This paper discusses the failure mode of the gearset and determines the root cause of such failure and how the new oil might (or might not) contribute to the damage.

11:30 am - 12 pm
3852012: Development of an Industrial Gearbox Relevant Micropitting Test
Marc Ingram, Thomas Baldwin, Ingram Tribology Ltd, Carmarthen, United Kingdom; Matthew Smeeth, Clive Hamer, PCS Instruments, London, United Kingdom

Micropitting is a type of surface fatigue mechanism where small pits are formed on the surface of gears. The formation of pits leads to a loss of material and a change of geometry on the surface of the gear tooth. This can cause macropits to form and ultimately failure of the part. In this paper we describe the development of a new micropitting test to evaluate the ability of lubricants to prevent micropitting. A three ring on roller test machine is used to investigate the mechanism of micropitting on case carburised 16MnCr5 parts. Different test conditions are investigated by varying the test lambda ratio (film thickness to surface roughness ratio) along with the direction and extent of sliding between the test parts. The roughness of the samples is monitored throughout the test, to balance mild wear, which has been shown to be a competing mechanism to micropitting. The test method is qualified using both simple additive blends and fully formulated oils.

3H 103C

Commercial Marketing Forum III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am - **Placeholder**

8:30 - 9 am - **Biosynthetic Technologies**

9 - 9:30 am
3824034: LANXESS Deutschland - A New VOC-free Temporary Corrosion Inhibitor, Bt Diluted in Water – a Contradiction?
Wilhelm Rehbein, Isabell Lange, LANXESS Deutschland GmbH, Mannheim, Germany

Corrosion turns out to be of even higher significance during the last decades. In a globalized world, transportation of parts by road or oversea becomes even more important, but also indoor and outdoor storage is still significant. The economic damage that is caused by corrosion shows quite impressive numbers, though effective rust preventatives are still of highest importance. Nowadays rust preventives based on organic solvents or mineral oil are widely spread and their application is well known. However, products that contain VOC are getting into a focus concerning health and environmental issues. Due to stricter guidelines and regulations it becomes crucial to develop products that are better adapted to environmental specifications. With Additin ® E 555 a rust preventative package was developed that is used with water as "solvent“. Its new VOC-free technology is in alignment with the latest trends towards sustainability and less impact to human health and the environment.

9:30 - 10 am
3831329: King Industries - Introducing KX460 – A High Performance Water-based Rust Preventive Additive for Formulations Demanding Superior Metal Parts Protection in Severe Corrosion Conditions
Clifford Pratt, King Industries, Inc., Norwalk, CT

Protection of metal parts against corrosion, including everything from small to large components, remains a critical element in the financial investment of parts manufacturing. Given the shift driven by environmental regulation from the market dominant oil-solvent based rust preventives to water-based formulations, a gap has emerged in products that provide adequate protection. KX460 is a rust preventive additive intended for use in water-based systems with superior performance in high humidity and salt containing atmospheres. Through a series of ASTM, DIN, and in-house tests, KX460 has demonstrated exceptional corrosion protection performance in addition to emulsion stability under stressed conditions. KX460 for water-based rust preventives combines performance, stability, and versatility expected in traditional RP systems without the concerns of handling volatile solvents.

10 - 10:30 am - **Break**

10:30 - 11 am - **Eastman Chemical Company**

11 - 11:30 am - **The Lubrizol Corporation**

11:30 am - 12 pm - **Munzing**

3I 104A

Electric Vehicles III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3808007: High Temperature Lightweight Al-alloys for EV Regenerative Brake Rotors
Tomas Grejtak, Amit Shyam, Janet Meier, James Haynes, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN; Peter Blau, Blau Tribology Consulting, Enka, NC

The next generation electric powertrain brakes require light weight, good resistance to wear, corrosion, creep, and heat, and high thermal conductivity. As an attempt to replace the traditional cast iron, this study investigated the feasibility of using advanced aluminum alloys for electric vehicle (EV) braking rotors. ORNL recently invented high-temperature Al-Cu-Mn-Zr (ACMZ) alloys with excellent microstructural and mechanical stability beyond 300 °C. Two versions of the ACMZ alloys with 6 and 9 wt% Cu, respectively, were tested on a sub-scale brake tester against a commercial brake lining material. Analysis was done based on combination of frictional, wear, and temperature responses, which are among the key factors for candidate brake rotor materials.

8:30 - 9 am
3818885: High-pressure Fuel Pump Performance With Low Lubricity Fuels Monitored With Acoustic Emission Technology
Nikhil Murthy, Vincent Coburn, Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

The high-pressure fuel pump (HPFPs) contained in many diesel engine fuel delivery systems is heavily impacted by the lubricity of the fuel. As newer synthetic fuels and biofuels become introduced into the market these concerns become more pronounced. In this study we seek to understand the effect of fuel viscosity and chemistry on performance and durability of HPFPs. A HPFP was operated with two low-viscosity (1 cSt) fuel components, ethanol and decane. Post-failure analysis was conducted to determine the extent of damage and root cause of failure. Additionally, acoustic emission sensors were used as an exploratory non-destructive method for early fault detection. A combination of position correlation and frequency analysis was used to identify the initiation of damage in the pumps.

9 - 9:30 am
3834898: Impact of High Speed of Rolling Element Bearings in Oil Lubricated Contacts
Farrukh Qureshi, The Lubrizol Corporation, Wickcliffe, OH; Azzedine Dadouche, Rami Kerrouche, National Research Council, Ottawa, Ontario, Canada

The transition from internal combustion engine- (ICE) powered vehicles to electric motor-powered vehicles is fundamentally changing lubricant requirements. Due to torque-speed characteristics of electric motor, the drivetrain is mechanically simpler. The input speeds for drivetrain components are much higher compared to conventional ICE driven transmissions. As a result, lubricating high speed bearings and gears becomes a challenge. Improved test capability for mechanical components is needed for evaluation and further development of lubricant/mechanical systems. This work attempts to develop knowledge on high-speed behavior of rolling element bearings under high-speed conditions. The results from this study indicate that high-speed bearing operation would result in significant temperature increase and may also cause skidding/sliding of rolling components leading to reduced life of such components.

9:30 - 10 am
3810703: A Novel Method of EV-Fluid Differentiation in Compatibility With Enameled-insulated Copper Wires
Annabelle Minz-Schuett, Minz Pruef + Test GmbH, Limburg, Germany; Joerg Fahl, Volkswagen AG, Wolfsburg, Germany

Hairpin technology is leading the way in the construction of highly efficient electrical motors for electrified mobility. A powerful and efficient e-motor requires a coating of the copper wires with sufficient surface strength. Special attention has to be paid to the insulation varnish regarding its compatibility with the surrounding lubrication oil / EV-fluid. In this context, an industry-wide demand for suitable material combinations of heat and lubricant resistance lacquer as well as compatible EV-fluid formulations is rapidly increasing. Inventing a method for qualifying suitable lacquer and fluid formulations was essential. The Volkswagen AG succeeded in developing a novel, very precise and quick method for the differentiation of specially designed EV-fluids in compatibility with insulation varnish formulations. This paper gives an insight on this project based on testing coated rectangular wires and the change in their mechanical properties.

10 - 10:30 am - **Break**

10:30 - 11 am
3848344: Multi-physics and Multi-scale Prediction of Tribological Behaviour of Electric Powertrain
Mahdi Mohammadpour, Loughborough University, Loughborough, United Kingdom

The tribology of automotive powertrains is facing significant changes in the range of working conditions including speeds and loads and consequently the applicable failure modes and lubrication regimes. This is due to rapid development of electrification in this industry, introducing novel landscape for this subject. To facilitate informed and objective design decisions at this demanding transitional stage, detailed and accurate methodologies are required. This may ultimately lead to ambitions vision of zero-prototype development. To achieve this goal, realistic prediction tools are required. This necessitates multi-physics method involving tribology, dynamics and electromagnetics. The method should embed a multi-scale approach to consider detailed physics-based phenomena at surface level which is the origin of tribological behaviour. In this paper, a multi-physics and multi-scale method is proposed for realistic predictions of modern electrified powertrains.

11 - 11:30 am
3829359: Performance Evaluation of Greases for Electric Vehicle Motors
Gabriel Calderon Salmeron, Sergei Glavatskih, KTH Royal Institute of Technology, Stockholm, Sweden; Johan Leckner, Axel Christiernsson Int. AB, Nol, Sweden

The electrification of the automobile industry demands high efficiency from all the electric vehicle (EV) systems and subsystems. Grease lubrication is one of these systems. However, measuring the grease lubrication frictional levels under EV conditions requires novel methods that represent accurately these conditions. Our previous publication [1] presented an experimental setup to measure frictional torque in grease-lubricated bearings. In this work, we expand this investigation in our high-speed bearing test rig, capable of measuring bearing friction and self-induced temperature, by evaluating Lithium, Polyurea and Polypropylene greases in closer EV motor conditions. 12 experiments of 28 days each were performed under an interesting range of variable and fluctuating speeds. The impact on sustainability was quantified by measuring the energy consumption for each of the grease candidates, providing an important insight into future experimentation with greases of EVs.

11:30 am - 12 pm
3811805: Ultrasonic Measurement of Interference Pressures for a Planetary Gear Shaft-bush Contact
Gary Nicholas, Rob Dwyer-Joyce, The University of Sheffield, Sheffield, United Kingdom; Hiroyuki Suzuki, Hino Motors Ltd., Tokyo, Japan

Planetary gearboxes are widely utilised in industry due to their high torque-to-weight ratio, compactness, low operating noise. The carrier within these gearboxes consists of shafts which are interference fitted into the carrier. Excessive contact pressure from the interference fit, high operational loading as well as microscopic sliding causes severe wear at these contact interfaces. This has been attributed to geometrical errors and operational loading of the shaft. As such, it was desirable to conduct a quantitative assessment of the pressures experienced at the carrier-shaft interface. In this work, ultrasonic waves generated using focused probes were used to measure the interference pressure of various steel shaft-sleeve specimens. The ultrasonic responses were initially calibrated using specimens of known interference pressures. Contact pressure measurements were subsequently carried out on two shaft-sleeve specimens designed to be representative of the shaft-carrier contact.

3K 201A

Metalworking Fluids III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3809212: Environmental Advantages of Sulfur Containing EP Additives in Metalworking Processes
Wilhelm Rehbein, Thomas Klein, LANXESS Deutschland GmbH, Mannheim, Germany

Sulfur carriers are well known as EP additives and for a long time have been successfully used in many types of metalworking fluids. They can be beneficially used in almost all kind of metalworking processes to prevent adhesive wear under boundary and mixed lubrication conditions. Compared to chlorinated paraffins, the frictional forces in certain metalworking processes are more than 25% lower by using suitable sulfur carriers. However, in addition to their superior protection against cold welding, sulfur carriers show many benefits in terms of toxicity, environmental impact and energy efficiency when compared to other EP additives. Many sulfur carriers are e.g. manufactured by sulfurization of natural, renewable raw materials like vegetable oils. The presentation will explain how sulfur carriers reduce the environmental footprint of metalworking fluids while maintaining or even increasing their performance and support the metalworking industry on their way to a more sustainable future.

8:30 - 9 am
3834082: How To Design A Sustainable Metalworking Fluid Formulation Using Renewable Base Fluids.
Jesse Ziobro, Univar Solutions, Houston, TX; Stephanie Cole, Clariant Corporation, Mount Holly, NC

The increasing interest in sustainable chemistry technology and biobased fluids are becoming more sought after than traditional petroleum-based lubricants. This paper dives into the three pillars of sustainability: economic, environmental, and social while defining what this means for a metalworking fluid formulation. For the economic pillar, the performance of the formulated metalworking fluid will be evaluated against standards. To address the environmental pillar, this paper will look into several renewable resources in place of nonrenewable resources. This presentation will show the design of experiments to formulate several water-dilutable metalworking fluids containing ingredients from renewable resources, and the testing associated with metalworking fluids to show performance characteristics.

9 - 9:30 am
3812454: Pick a PAG, Any PAG: Selecting Polyalkylene Glycols for Synthetic Coolants
Zach Magness, Calvary Industries, Fairfield, OH

Polyalkylene glycols (PAGs) form the classic lubricity base for synthetic metalworking coolants. These materials come in a wide variety of solubilities, molecular weights, starter molecules and final structures. With so many options, why choose one material over another? This paper will compare final coolant properties when using different PAGs including foam and lubricity.

9:30 - 10 am
3815117: Total Rehab of a Metalforming Fluid System in a Tube Mill Machine
Arturo Cardenas, Oltec, San Luis, SLP, Mexico

When the pandemic arrived in America, the industry in Mexico decided to stop their plants for at least one to two months (March-April 2020) in order to try to break the contagious chain. This meant leaving some deposits of metalworking fluids unattended, allowing the growth of every kind of microorganism (Bacteria, Fungi, yeasts, lichens, etc.). After that, when the industry tried to come back to work, they had to deal with this enormous problem considering that the low production levels did not allow them to invest in a fresh charge. After a year of working in such conditions, they finally decided to plan the changing of the fluids, but at that moment, the problem had become catastrophic. In this paper, we will analyze how atypical factors can severely impact metalworking fluids and then affect the production levels in the industry and also how they were remedied. Also, we will discuss (briefly) the best practices to preserve this kind of system in the best conditions.

10 - 10:30 am - **Break**

10:30 - 11 am
3811678: Development of a Benchtop, Tribological Test to Emulate Metal Cutting
Syed Ashir Sajid, Rob Dwyer-Joyce, University of Sheffield, Sheffield, South Yorkshire, United Kingdom; Christopher Taylor, AMRC with Boeing, Sheffield, United Kingdom; Thawhid Khan, Manchester Metropolitan University, Manchester, United Kingdom

On route to commercialisation, MWFs are subjected to extensive testing regimes consisting of tribological bench tests and full-scale production tests. Despite this, current tribological bench tests in industry provide a weak correlation with real machining processes. As a result, MWF manufacturers are often forced to rely on costly validation trials when determining fluid performance. In response, this study aims

to develop a novel, tribological, benchtop test that can emulate metal cutting, serving to establish the impact of varying MWF compositions for stainless steel, mild steel & aluminum. In doing so, a research methodology is developed which seeks to bridge the gap between tribological bench testing and machining processes. The methodology provides a fluid performance indicator that will allow companies to carry out cost-effective tests to give instant results and to understand how the MWF technology behaves in a fundamental aspect to accelerate product development further.

11 - 11:30 am
3834110: Boundary Lubricant Additive Response Comparisons Between Aluminum and Copper Alloys Using Twist Compression Tests (TCT)
Ted McClure, Sea-Land Chemical / SLC Testing Services, Westlake, OH; Alexes Morgan, Sea-Land Chemical Co, Westlake, OH

Electric vehicles (EV) require changes in the way vehicles are manufactured, the metalworking fluids used, as well as lubricants used in operation. Electric current and heat management are important considerations, involving copper and aluminum. Aluminum content of continues to increase in auto body structures for lightweighting purposes. The Twist Compression Test (TCT) is a bench test that creates lubricant starvation under high pressures and sliding contact. It is used to evaluate the boundary lubrication performance of lubricants and galling resistance of material couples. This presentation is an extension of work presented at STLE in 2022. TCT is used to evaluate a series of boundary additives on automotive body aluminum and copper. Additive responses with the two metals will be compared. Boundary additives evaluated include polymers, esters, and fatty acids, alcohols, and amines. The aim is to provide useful data for formulation.

11:30 am - 12 pm
3812650: The Aminolysis and Hydrolysis of Esters in Water Dilutable Metalworking Fluids
Karl Zhong, Quaker Houghton, Wayne, PA

Esters are affective boundary lubricants in metal working fluids (MWFs) and function to reduce tool wear and improve the surface quality of machined parts. However, esters in MWFs tend to undergo chemical reactions over time. These reactions may adversely affect the performance of a MWF – particularly in terms of lubricity, emulsion stability, foam tendency and product shelf life. The predominant reactions of esters in water dilutable MWFs are aminolysis and hydrolysis. In this study, we investigated aminolysis and hydrolysis of esters in a typical water dilutable MWF. The aminolysis and hydrolysis reactions were monitored by respective changes in the product's alkalinity and acidity. In addition to this kinetic information, the effect that aminolysis and hydrolysis have on each ester's lubricity , emulsion stability, and foam tendency were also investigated.

3N 202B

Nanotribology III

Session Chair: Mehmet Baykara, University of California Merced, Merced, CA
Session Vice Chair: TBD

8 - 9 am
3832034: Invited Talk: Superlubricity: Toward Design of Zero-Friction and Zero-Wear Materials
Diana Berman, University of North Texas, Denton, TX

In this presentation, we overview recent advances in establishing the fundamental understanding of materials interactions at sliding interfaces and use this knowledge as a guide to developing nanomaterials solutions that enhance reliability and efficiency of tribological systems. We evaluate tribological performance of nanostructured materials, including combinations of various 2D materials, and demonstrate realization of superlubricity regime at macroscale. To extend the lifetime of the tribological materials, we demonstrate tribochemically-driven self-replenishment of materials inside the contact interfaces, thus enabling a zero-wear sliding regime. Overall, the findings have not only allowed us to solve some long-standing puzzles, but could also open a new avenue for the development of new concepts and design strategies for next generation of tribologically efficient materials systems.

9 - 9:30 am
3811864: Speed Dependence of Friction in the Structural Superlubricity Regime
Wai Oo, Mehmet Baykara, University of California Merced, Merced, CA

Structural superlubricity constitutes an intriguing, intrinsic lubrication mechanism for small-scale mechanical systems, whereby incommensurability at the interface results in vanishingly small friction forces. Despite significant research progress in recent years, many open questions remain regarding the physical limitations of this unusual phenomenon. Here, we present experimental results on the speed dependence of friction forces in the structural superlubricity regime. In particular, we perform manipulation experiments on gold nanoislands on graphite by way of atomic force microscopy. Results point toward a linear increase of friction force with sliding speed instead of the much more common logarithmic dependence, supporting theoretical predictions based on the concept of “thermal drift” [1].
[1] K.B. Jinesh et al., Phys. Rev. B 78, 155440 (2008).

9:30 - 10 am
3811155: Role of Contact Line in Structural Lubricity Breakdown
Hongyu Gao, Universität des Saarlandes, Saarbrücken, Germany

Structural lubricity describes a state of ultra-low friction between two well-defined contact surfaces that are incommensurate so that energy dissipation is systematically annihilated. In the case of manipulating islands at nanometer length-scale, such a low-friction state can be under the influences of, e.g., relative rotational/sliding orientation, island geometry and dimensions. In this report, by means of molecular dynamics, we demonstrate that instabilities can be introduced from quasi-discontinuous dynamics of the Moiré patterns near a propagating contact line while sliding a gold island on a HOPG substrate. Such discontinuity can be attributed to the symmetry breaking nature of a multi-layer gold with its (111) surface parallel to graphite basal plane. The elevated mean fictional forces exhibit only weak dependence on the sliding speed, or namely Coulomb-type friction according to Prandtl.

10 - 10:30 am - **Break**

10:30 - 11 am
3810593: Single-asperity Sliding Friction Across the Superconducting Phase Transition
Andre Schirmeisen, Dirk Dietzel, Justus-Liebig University, Giessen, Germany; Wen Wang, Southwest Jiaotong University, Chengdu, China

In sliding friction, different energy dissipation channels have been proposed, including phonon and electron systems, plastic deformation, and crack formation. Here, we present friction experiments of a single-asperity sliding on a high-T_c superconductor BSCCO from 40 to 300 kelvin. Overall, friction decreases with temperature as generally expected for nanoscale energy dissipation. However, we also find a large peak around T_c. We model these results by a superposition of phononic and electronic friction, where the electronic energy dissipation vanishes below T_c. In particular, we find that the electronic friction constitutes a constant offset above T_c, which follows a power law in agreement with Bardeen-Cooper-Schrieffer theory. Furthermore we found a strong influence of step edges on the superconducting friction signal, which is due to different cleavage planes of the BSCCO crystal. This shows that friction on superconductors is extremely sensitive to the atomic surface structure.

11 - 11:30 am
3815745: Investigating Nanotribological Behavior of Graphitic surfaces in the Binary Mixtures of hexadecane and cyclohexane
Prathima Nalam, Thomas Bui, Bhadrakalya Pathirannehelage, Luis Velarde, SUNY University at Buffalo, Buffalo, NY; Behnoosh Baboukani, University of California Berkeley, Berkeley, CA

In this study, we select alkane solvent mixtures of n-hexadecane (linear, in-plane structure) and cyclohexane (aromatic, staggered structure) to tune the structural order of the solvated layers in the vicinity of multilayer graphene and fused silica. Vibrational Sum Frequency Generation (vSFG) measurements show n-hexadecane chains undergo a transition from a slight-tilt configuration at lower concentrations (<40 wt.% in cyclohexane) to flat-lying molecules as the concentration of hexadecane was increased. By measuring the changes in gauche defects and surface coverage by hexadecane at the interface in solvent mixtures, higher alkane ordering and adsorption-free energies were observed on multilayer graphene compared to the silica surface. A similar transition in friction measurements, i.e., at 40 wt.% hexadecane in cyclohexane, was measured using a single-asperity atomic force microscope probe on graphitic surfaces, indicating a direct influence of structural order on friction.

11:30 am - 12 pm
3834279: Connecting Interfacial Structure and Friction for Graphene-based Interfaces
Li Yuan, Daniel Sanchez, Robert Carpick, University of Pennsylvania, Philadelphia, PA; Ashlie Martini, University of California, Merced, Merced, CA; Suzhi Li, Xi'an Jiaotong University, Xi'an, China; Graham Cross, Trinity College Dublin, Dublin, Ireland

Interfacial structure significantly affects the frictional behavior of graphene. We endeavor to connect atomic-scale interfacial characteristics with graphene's frictional behavior. First, we perform molecular dynamics simulations of friction for a Si tip sliding on substrate-supported graphene. Different graphene/substrate interfacial atomic registries are obtained by varying the substrate surface roughness. Rougher substrates allow better registry, decreasing tip/graphene friction. As well, local substrate roughness affects tip-graphene friction, rivaling the known strengthening effect associated with graphene's layer-dependent friction. We also experimentally study the crystallographic orientations of graphene pleats formed by the self-folding of graphene. Interfacial commensurability is determined by lattice-resolved lateral force images. This highlights how interfacial organization strongly affects friction in graphene-based systems.

4A 101A

Lubrication Fundamentals IV: Polymers

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3810988: Same Engine - less CO_2. Lubricant Solutions to Maximize Fuel Economy Without Compromising Oil Consumption.
Seemann Michael, Phil Hutchinson, Thomas Schimmel, Sabrina Strube, Evonik Specialty Chemicals, Singapore, Singapore; Ellington JoRuetta, Evonik Oil Additives USA, Inc., Horsham, PA

Improving fuel efficiency is a major goal of the automotive industry. A common approach to improve fuel economy is the adoption of lower viscosity engine oils, however this approach raises durability concerns and may require engine re-design. A new approach is to increase the Noack evaporation loss limit combined with advanced viscosity index improvers like comb polymers. Studies demonstrate that a 0W-20 engine oil at 21% Noack can even deliver higher FE than a 0W-16 oil. Increased Noack volatility might raise concerns of higher oil consumption. Therefore, Evonik investigated oil consumption in a state-of-the-art engine using a broad test matrix including multiple Noack volatilities, SAE viscosity grades, and base stocks. All parameters showed poor correlation with engine oil consumption, suggesting that Noack volatility is a poor indicator of oil consumption. This new approach allows maximized fuel efficiency within the same SAE grade through optimized viscometric performance.

2:30 - 3 pm
3832539: Dual Functional Additives: Polymer Adsorption and Boundary Effects.
Amran Mohamed, Janet Wong, Imperial College London, London, United Kingdom; Sarah Matthews, Shell Global Solutions (UK) Ltd, London, United Kingdom

Due to increasing environmental concerns, there is a growing need towards multi-functional additives in lubricant formulations. Polymeric additives, due to their flexible molecular design, are good candidates for multi-functional additives. Whilst they are commonly used as viscosity modifiers, they may also adsorb on surfaces and provide boundary lubrication, i.e. act as friction modifiers. This dual functionality is controlled via modifications of the polymer's chemistry and architecture. In this study, using dissipative particle dynamics (DPD) simulations, along with quartz crystal microbalance (QCM) to provide experimental validation, the impact of polymer adsorption on the shear behaviour of the polymer solution is investigated. In our QCM experiments we find that the block copolymers, which aggregate in bulk, can adsorb onto the metal surface to form a viscous layer. Through modelling we investigate this viscous layer, and the implications of this on the solution's shear response.

3 - 4 pm – Exhibitor Appreciation Break

4 - 4:30 pm
3829833: Low Temperature Viscometrics and PPD Effect on Group III Base Oils
Jacob Scherger, Functional Products Inc, Macedonia, OH

Pour Point Depressants (PPD's) are designed to improve low temperature performance[1], and picking the right PPD for the right application is crucial to maintaining low temperature fluidity to prevent lubricant starvation and part damage as well as to increase efficiency during low temperature start and operation. Here several different PPD chemistries as well as different wax affinities within the same chemistry have been screened for their effectiveness in a variety of API Group III base oils. Both pour point and dynamic viscosity were used as metrics of comparison. It was found that being tuned to a specific wax profile is more important than specific PPD chemistry, and there can be significant differences in an oil's PPD response even amongst the same API group. Further, the reliability of pour point testing as a screen for low temperature viscosity was evaluated.
[1]L.R. Rudnick. Lubricant Additives Chemistry and Applications: Third Edition. CRC Press, 2017.

4:30 - 5 pm
3833360: Viscoelasticity of Lubricants With Polymer Additives Sheared in Nanogaps and Their Temperature Dependence
Shintaro Itoh, Takumi Nozue, Kenji Fukuzawa, Naoki Azuma, Hedong Zhang, Nagoya University, Nagoya, Japan

Lubricant viscosity is becoming lower to improve the fuel efficiency of automobiles. As lubricant viscosity decreases, the load capacity becomes smaller, resulting in narrower sliding gaps, leading to wear and seizure. Therefore, developing low-friction technology in boundary lubrication conditions while achieving low-viscosity lubricants is an urgent issue. A previous study reported that adding polymers to lubricating oil reduces friction in boundary lubrication conditions. The authors successfully measured the shear viscoelasticity of lubricants with a polymer additive by shearing it in a nanogap. The results showed that the adsorption layer of polymers has a significant effect on the nanogap. Specifically, the viscosity index increased compared to the bulk state, and a mechanical response suggestive of rubber elasticity was detected. The results of this study provide fundamental insight into the molecular design of polymer additives and the understanding of lubrication phenomena.

5 - 5:30 pm
3832683: Effect of Polarity of Polymer Additives on Their Adsorption and Boundary Film Formation
Yuxi Song, Kenji Fukuzawa, Shintaro Itoh, Naoki Azuma, Hedong Zhang, Nagoya University, Nagoya, Japan; Tomoko Hirayama, Naoki Yamashita, Kyoto University, Kyoto, Japan

Blending oil-soluble polymer additives into lubricant base oils has been employed as an effective way to improve boundary lubrication performance. In this study, we directly measured the thickness and the gap during sliding of nanometer-thick adsorbed polymer films using vertical-objective-type ellipsometric microscopy (VEM) and neutron reflectometry. The structure and boundary film formation ability of adsorbed films formed by polyalkylmethacrylate (PAMA) polymers with different polarities were investigated. It was found that with the increase in the polarity of the polymers, more loosely adsorbed chains (loops and tails) in the adsorbed films were found. These loosely adsorbed chains temporarily trapped free polymer chains flowing into the gap between sliding surfaces, resulting in a thicker boundary film.

5:30 - 6 pm - **Lubrication Fundamentals Business Meeting**

4B 101B

Rolling Element Bearings IV

Session Chair: Alexander Fletcher, AFRL/RQTM, Wright Patterson Air Force Base, OH
Session Vice Chair: Kushagra Singh, Purdue University, West Lafayette, IN

2 - 2:30 pm
3801800: Atomistic Investigation of White Etching Bands Transformations in Rolling Element Bearings
Mostafa El Laithy, Ling Wang, Terry Harvey, nCATS, Southampton, United Kingdom; Bernd Vierneusel, Schaeffler Technologies AG & Co. KG, Schweinfurt, Germany

Rolling contact fatigue-induced microstructural transformations in bearing steels like dark etching region (DER) and white etching bands (WEBs) results from complex rearrangement processes at the atomic level. Detailed insights into the material structure recently resulted in a unified mechanism, showing that these features develop due to cyclic energy build-up and release processes leading to the formation of ferrite grains and lenticular carbides. Now, further analysis on the WEBs using transmission electron microscopy and atomic probe tomography has revealed that the bands consist mainly of equiaxed ferrite grains, while lenticular carbides are associated with elongated ferrite grains. The analysis shows carbon segregating at equiaxed grain boundaries, and carbon migration from these boundaries is observed during grain rotation/coalescence. These results are further important contributions to a deeper understanding of the mechanisms involved in the formation of DERs and WEBs.

2:30 - 3 pm
3811078: Initiation And Drivers of Butterfly And White Etching Area Manifestation In Bearing Steels
Mostafa El Laithy, nCATS, Southampton, United Kingdom; Ling Wang, Terry Harvey, University of Southampton, Southampton, Hampshire, United Kingdom; Alexander Schwedt, Joachim Mayer, RWTH Aachen University, Aachen, Germany; Wolfram Kruhoeffer, Schaeffler Technologies AG & Co. KG, Herzogenaurach, Germany

Butterflies and white etching cracks (WECs) have been commonly linked with RCF premature failure in bearings within various applications. Butterflies typically develop around stress raisers such as non-metallic inclusions (NMIs) and voids, where wings of white etching areas (WEAs) initiate at the interface between the inclusion and the steel matrix. It has been suggested that manifesting of butterflies is one of the formation mechanisms of WEC. Despite the large number of studies on butterflies decades ago, their formation mechanisms and the links between butterflies and WEC remain unclear. This study investigates the development of butterflies formed in roller bearings under a range of stress conditions. The initial results have shown that shear stress has a significant influence on the formation frequency of butterflies but can limit their further growth. Also, inclusion type, such as sulphides, oxides and duplex inclusions, has been found to influence the formation of butterflies.

3 - 4 pm – Exhibitor Appreciation Break

4 - 4:30 pm
3830596: Thermal Simulation of Bearing Components in Customer Applications.
Travis Shive, Fabrizio Mandrile, SKF USA Inc, Lansdale, PA

Bearing temperatures are a direct influence of bearing operating clearance or preload. The relationship of temperature from inner ring, through rolling element, to outer ring is the driver for the forementioned clearance or preload. Traditionally the temperature relationships are defined at a pre-selected value having the rolling elements halfway between the inner and outer ring temperature for most cases. Since this isn’t always the proper condition, software advancements allow the simulation of bearing component temperatures. This would include inner ring, rolling elements and outer ring. Software for simulating bearing temperature can account for various system configurations and mating components surrounding the bearings. This understanding of bearing temperatures in various applications and designs provides ability to optimize bearing design and improve performance.

4:30 - 5 pm
3832888: Comparison of Thermal Characteristics of an Aero-Engine Cylindrical Roller Bearings: All-Steel Versus Hybrid
Azzedine Dadouche, Rami Kerrouche, National Research Council, Ottawa, Ontario, Canada; Salah Boukraa, University of Blida1, Blida, Algeria

Modern aircraft engines have to meet rigorous requirements, such as thrust to weight ratio, efficiency and environment protection. These requirements affect all engine modules and components, including rolling-element bearings. The latter have to withstand extreme operating conditions because of the high thermal impact due to elevated rotational speeds and loads. In this study, a series of experimental measurements

were carried out under realistic operating conditions of load, speed and oil flow rate to investigate and compare thermal characteristics of two of cylindrical roller bearings: an all-steel (M50/M50-Nil) and a hybrid roller bearings. The latter features silicon nitride (Si_3N_4) rollers. A high speed bearing rig was used to conduct the experiments. An array of twelve thermocouples, equally distributed around the circumference of the outer ring, was used to measure the thermal profile within the bearing. Oil supply and drain temperatures were also measured during the rig tests.

5 - 5:30 pm
3808858: Simulation of Temperature Distribution in Rolling Bearings
Hannes Grillenberger, Philipp Rödel, Yunsheng Huang, Schaeffler Technologies, Herzogenaurach, Germany

The temperature and heat generation in rolling element bearings are important criteria of these machine elements – especially in context of sustainability and energy saving. However thermal calculations during the design process are usually not done, as the typical state of the art is based on finite element or transient calculations which could produce high quality results but take long time and high computer power. Additionally, the thermal characteristics of the rotating rolling contact are hard to represent in these methods. However, the need for accurate thermal characteristics of a bearing is high to optimize the system. The presentation will present a new method that returns the temperature distribution inside a bearing as well as the heat transfer according to thermal boundary conditions and frictional energy. As it is based on quasi-static calculations and is for steady state results only, it converges quickly and can be used for optimizations and handled by a large user group.

5:30 - 6 pm
3834108: Investigation of Heat Generation in Ball Bearings for Liquid Rocket Engine Turbopumps
Hiromitsu Kakudo, Satoshi Takada, Japan Aerospace Exploration Agency, Kakuda-shi, Japan

Ball bearings supporting the main shaft of rocket engine turbopumps which supply cryogenic propellants to the main combustion chamber are critical elements of a rocket vehicle. Inside a turbopump, a portion of propellant is circulated in order to cool ball bearings that are self-lubricating ones using polytetrafluoroethylene as a lubricant. Heat generation of ball bearings rises the coolant temperature which affects its density and mass flow rate. Therefore, it is important to predict the heat generation precisely. In this research, heat generation in turbopump bearings is measured and compared with one theoretically predicted on a numerical model.

6 – 6:30 pm - **REB Business Meeting**

4C 102A

Fluid Film Bearings II

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3830467: Nonlinear Dynamics of an Accelerating Rotor Supported on Self-acting Air Journal Bearings
Manas Pattnayak, Jayanta Dutt, Raj Pandey, Indian Institute of Technology Delhi, Delhi, India

Self-acting air bearings are used in several high-speed micro-turbomachines, where frequent acceleration/deceleration of the rotor is common. The whirl amplitude of the rotor must be kept within tolerable limits for safe operations of the system. This research presents, for the very first time, the dynamics of an accelerating rotor supported on self-acting air journal bearings. Due to the rotor unbalance, the dynamics between the translational and spin coordinates get nonlinearly coupled. The work utilizes these coupled equations to plan appropriate acceleration schedules to limit the whirl amplitude and frequency as low as possible. Based on the research, it is found that in the presence of rotor unbalance, the acceleration should be scheduled in at least three regimes: the first with the maximum torque, the second with the minimum torque, and the last with an intermediate torque.

2:30 - 3 pm
3829137: Observation of Polymer Chain Deformation in Oil Under High Shear
Tatsuya Kusumoto, Moritsugu Kasai, Idemitsu Kosan Co.,Ltd, Ichihara-Shi, Japan; Mikihito Takenaka, Kyoto University, Institute for Chemical Research, Kyoto, Japan

Fluid resistance and oil film formation on the lubrication surface in engine oil are important issues in improving engine oil performance. However, the viscosity measurement of the engine oil with polymer is insufficient to clarify the fluid resistance and oil film formation. We thus made a novel cell that enables us to measure the polymer orientation under high shear rates by using small-angle X-ray scattering (SAXS). We have succeeded in visualizing the orientation process of polymer molecules under high shear rates by using the cell with synchrotron SAXS at SPring-8, Japan.

3 - 4 pm - **Exhibitor Appreciation Break**

4 - 4:30 pm
3833882: On the Experimental Performance of Additively Manufactured Hybrid Fluid Film Bearings
Keun Ryu, Junwon Heo, Minsoo Wee, Yeseul Kim, Jihan Kim, Hyunsung Jung, Homin Lim, Hanyang University, Ansan, Gyeonggi-do, Republic of Korea

New types of hybrid (hydrostatic plus hydrodynamic) fluid film journal and thrust bearings are designed and fabricated using direct metal laser melting (DMLM) technology with Inconel 718. The bearings include unique features combining multiple feeding holes or porous layers on the bearing surfaces and compliance of each pad structure. Static and dynamic load characteristics of the test journal and thrust bearings are measured using various test fluids (air, cold and hot water, and cryogenic liquid nitrogen) at various rotor speeds, supply pressures, and static/dynamic load conditions. The reliable performance of the additively manufactured hybrid fluid film bearings offers a remarkable opportunity to be implemented in future high-performance turbomachinery.

4:30 - 5 pm
3833660: Multi-Objective Taguchi-Grey Relational Analysis of Bearing Parameters on The Steady-State Performance of Three-Lobe Journal Bearing Lubricated With Non-Newtonian Fluid And Operating With Slip/No-Slip Conditions
Amar Ambekar, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, Karnataka, India

Multilobe bearings have potentially enhanced the system's stability due to multiple converging regions formed by their unique geometry. The slip length and power law index of the non-Newtonian lubricant are critically important in the design of journal bearings. Taguchi-Grey relational-based optimization techniques are used in the current research to find the optimal combination of parameters such as preload factor, slip length, and power law index to optimize the steady-state performance characteristics of three-lobe journal bearings. The approach considers three levels of slip length, a power-law index, and preload factor. According to the numerical analysis, the preload factor has the most significant effect on side leakage, accounting for approximately 86% of the total influence of independent parameters on steady-state characteristics. The power law index has a 77% influence, while slip has a 45% and 48% influence on non-dimensional load and friction variable, respectively.

4D — 102B

Materials Tribology IV

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3812323: Investigating the Effect of Solid Lubricant Inclusion on the Friction and Wear Properties of Laser Sintered Polyamide-12 Components
Kieran Nar, University of Sheffield, Sheffield, United Kingdom

The processing of Nylon-12 by Laser Sintering (LS) is one of the most well-established Additive Manufacturing (AM) processes for producing functional components. However, its further adoption remains hindered by an incomplete understanding of resultant part quality and the impact this has on component wear. Therefore, the scope of this research project is to investigate the tribological performance of LS Nylon-12 components. Recently, focus has transitioned to exploring solid lubricant inclusion within Nylon-12 feedstock prior to Laser Sintering. More specifically, individual composite powders filled with one weight percentages of PTFE and MoS_2 were shown to significantly reduce coefficient of friction and specific wear rate by as much as 50% and 78%, respectively, without compromising resultant part mechanical performance. Future work will evaluate different configurations of solid lubricant inclusion within Nylon-12 to optimise coefficient of friction and specific wear rate reductions.

2:30 - 3 pm
3834332: Dry Sliding Wear of Additively Manufactured Polymers
Joseph Berbach, Andrew Kelley, Harman Khare, Gonzaga University, Spokane, WA

Additive manufacturing (AM), often referred to as 3D printing, has revolutionized the process and capabilities of modern engineering design. 3D printing with polymeric materials has allowed for the fabrication of engineering prototypes, as well as specialized end-user components with optimized strength to weight. Despite these advances, development of polymeric 3D printing has largely focused on improving mechanical or thermal properties of printed parts. The efficacy of these polymers and processes for applications which require low friction and wear remains largely unexplored. In particular, it is unclear how the chemistry of polymers traditionally used in 3D printing affects their tribological function. This work is aimed at developing a framework for characterizing and understanding the tribological performance of AM-relevant polymeric materials, in order to predictively develop AM-compatible polymer-based materials with tunable tribological properties.

3 - 4 pm – Exhibitor Appreciation Break

4 - 4:30 pm
3811709: Comparing the Performance of Molded vs. Machined High-Performance Plastics in Unlubricated Friction and Wear Environments
Tanner Alauzen, Allegheny Performance Plastics, Pittsburgh, PA

Plastic prototype parts can save money, save time, and demonstrate part functionality. In the automotive sector, plastic parts are injection molded due to high annual volumes. To avoid long lead times of producing prototype molds, engineers consider machined prototypes for design validation. In friction and wear environments, engineers commonly avoid choosing plastic machined parts to validate design functionality. Engineers neglect machined parts over injection molded parts due to the different plastic manufacturing methods and additives being exposed due to the machining process. Two high performance plastics will be used to evaluate the difference between molded and machined parts. Factors such as overall part performance, wear rate, coefficient of friction, temperature, and surface finish will be evaluated. This study will aim to determine if there are significant differences between molded and machined plastic parts in friction and wear environments.

4:30 - 5 pm
3831322: Tribological Study of Oil-lubricated Thick Polydopamine + Polytetrafluoroethylene + Cu Nanoparticle Coatings
Sujan Ghosh, Min Zou, David Huitink, Hayden Carlton, Charles Miller, University of Arkansas Fayetteville, Fayetteville, AR; Samuel Beckford, German Perez, SurfTec, Fayetteville, AR

The tribological performance of oil-lubricated thick polydopamine (PDA) + polytetrafluoroethylene (PTFE) + Cu nanoparticle (NP) coatings and the effect of Cu NPs on the coating thermal conductivity were studied. Three aqueous PDA + PTFE + Cu NPs solutions were sprayed on cast iron containing 0.12, 0.25, and 0.50 wt.% of Cu NPs, respectively. The samples were annealed using a 3-step heating process and compacted to about 45 μm thickness using a hot press during the last heating step. Adding 0.25 and 0.50 wt.% Cu NPs improved the coating durability in oil by 52% and 33%, respectively. The improved durability was attributed to the better mechanical properties, stronger coating adhesion, and more thorough cross-linking of PDA and PTFE facilitated by the Cu NPs. In addition, adding Cu NPs also improved the coating thermal conductivity, with the PDA + PTFE + 0.25wt.%Cu coating showing a 12% improvement.

5 - 5:30 pm
3832482: Mechanistic Understanding of Substrate Roughness Effect and Coating Cohesion on the Scratch Resistance of Polytetrafluoroethylene-based Thin Coatings
Charles Miller, Min Zou, University of Arkansas at Fayetteville, Fayetteville, AR

Combining nanoindenter scratches and scanning electron microscopy of the scratches, a mechanistic understanding of the effect of substrate roughness on the scratch resistance of polytetrafluoroethylene (PTFE) thin coatings without and with graphite particles was obtained. The mechanical interlocking of the coating and substrate roughness was crucial for reducing tensile stresses in the coating that lead to tearing and global delamination. Furthermore, incorporating graphite particles improved the coating cohesion and coating compaction. The combined effects of substrate roughness and graphite particles in the PTFE layer enabled the coatings to endure high contact pressure nanoindenter scratches. This behavior shows promise for applying these solid lubricant coatings to bearing and gear applications in demanding conditions.

4F 103A

Environmentally Friendly Fluids III

Session Chair: Brajendra Sharma, USDA/ARS/NEA/ERRC, Wyndmoor, PA
Session Vice Chair: Daniel Garbark, Battelle Memorial Institute, Columbus, OH

2 - 2:30 pm
3811848: How Polyalkylene Glycols Save Energy in Industrial Gear Application – A Sustainable Case Study
David Schaeffel, Stephanie Cole, Clariant Corporation, Mount Holly, NC

Synthetic industrial gear oils have gained market share against mineral oil-based gear oils because of the drive toward increased productivity and reduced costs. Smaller gearboxes and reduced oil reservoirs coupled with the trend of higher loads and the extension of oil change intervals make the utilization of high-performing base stocks inevitable. Polyalkylene Glycols (PAGs) offer a unique set of properties based on their polar structure. PAGs provide cleaner operations, resistance against water contamination, and superior load-carrying and lubrication properties. PAGs are primarily synthesized from raw materials originating from crude oil and are not regarded as very sustainable base oil. We have assessed the potential environmental impacts of one particular PAG production vs. its benefits due to lower friction, i.e., energy savings in the use phase in a case study example.

2:30 - 3 pm
3817741: Tribological Performance in High Pressure Carbon Dioxide Environment for Compressor Application
Ayesha Asif, Ahmad Amiri, Andreas Polycarpou, Texas A&M University, College Station, TX

Since the early-mid 2000's there has been a renewed interest in environmentally friendly refrigerants with reduced or zero Global Warming Potential. While there have been significant advances with HFO 1234yf, CO_2 as a refrigerant (R744) is still the most widely abundant and inexpensive refrigerant. The initial challenges remain of operating under much higher pressures including supercritical conditions. In supercritical phase, CO_2 can exhibit a low viscosity and high density but pressurizing beyond the critical point (31.1°C, 1081 psi) is challenging. In this study, we revisit the lubricity of CO_2 refrigerants under newly formulated POE(Polyolester) and PAG(Polyalkylene Glycol) lubricants. Additionally, the effect of lubricant was combined with various friction and wear-reducing polymer coatings. The best tribo-pairs were evaluated based on the impact of using lubricant oils in combination with the coatings under different CO_2 environments.

3 - 4 pm - **Exhibitor Appreciation Break**

4 - 4:30 pm
3831911: Novel Green Friction Modifiers for Aqueous Lubricants
Sam Davison, Joseph Lanigan, University of Sheffield, Sheffield, United Kingdom

It is estimated that 50% of all of the lubricants produced today are lost into the environment. Novel, green lubricants are a necessary technology to protect the environment for future generations while simultaneously demonstrating excellent lubricity with the potential to reduce frictional energy losses. Oil based lubricants can be biodegradable, some of which are very well established. Water based (or aqueous) lubricant systems are being explored as an alternative, especially in maritime applications. Poor mixed-lubrication performance especially at bearing start-up holds back aqueous and water based lubricants when compared to oils. Friction modifiers are part of the key to this current tribological challenge to facilitate a shift away from (carbon intensive) oil lubricated systems with effective, more environmentally friendly additives. Unique friction modifiers and viscosity index improvers are available for experimental testing with friction and wear assessment.

4:30 - 5 pm
3833026: Investigating the Effect of Novel Processing Routes in Enhancing the Tribological Behavior of Soybean Oil
Piash Bhowmik, Clement Tang, Sougata Roy, University of North Dakota, Grand Forks, ND; Brajendra Sharma, Majher Sarker, USDA/ARS/NEA/ERRC, Wyndmoor, PA

Due to renewability, biodegradability, good viscosity and non-toxicity, soybean oil is being used as lubricating oil in various sectors. The purpose of this research is to formulate lubrication oil using soybean oil which will be used for next generation automotive, aerospace and UAV sectors. In this study, raw soybean oil was additized with phosphonium cation based ILs and characterized using FTIR and NMR spectroscopy. Oxidation and mass stability were analyzed using a pressure differential scanning calorimeter (PDSC) and Thermogravimetric analysis (TGA) respectively. The tribological behavior of raw and modified soybean oils was investigated with silicon nitride ball and AISI 52100 steel flat under high frequency on ball and flat reciprocating sliding machine from ambient temperature to 100C. The wear tracks were evaluated using the surface profilometry, and SEM-EDS analysis to reveal the wear mechanisms under different lubricated conditions.

4G 103B

Gears II

Session Chair: Nikhil Murthy, DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD
Session Vice Chair: Pinzhi Liu, ExxonMobil Research and Engineering, Annandale, NJ

2 - 2:30 pm
3831228: Industrial Gear Efficiency Demonstration
Andrew Gant, Afton Chemical Ltd, Bracknell, Berkshire, United Kingdom

This work aimed to bring in-house full scale instrumented gearbox efficiency measurement capability and to establish the main determinants of efficiency in terms of both gearbox operating characteristics and fluid componentry. Discrete project stages can be summarized as: MTM Stribeck curve trend identification as per lubricant base oil and additive pack and identifying operating regimes in the full size gearbox which produce the greatest lubricant discriminability; Examination of the deconvolution of specific additive pack chemistries in synthetic base oils and synthetic PAO constituents in terms of boundary, mixed and full EHL lubrication regimes; and Identify correlations of gearbox mechanical power losses with the lubricants' pressure-viscosity coefficients.

2:30 - 3 pm
3833949: Performance Enhancement of Plastic Gears – the Potential of Laminated Woven-Carbon-Fiber Einforced Plastics
Damijan Zorko, Zoran Bergant, Borut Černe, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia

Laminated composites have so far received little attention as a potential material for gear transmissions. In the study, the potential of autoclave cured woven carbon fiber reinforced plastic (CFRP) composite gears was investigated by a combination of experimental and numerical methods. Test gears were milled from a high-quality, autoclave cured, woven carbon fiber reinforced epoxy composite plate, and tested in

mesh with a steel pinion on a gear testing rig. The employed methods enabled the identification of the composite's mechanical, thermal, and tribological characteristics, as related to the studied gear pair application. Failure mechanisms were studied by employing a scanning electron microscope and a high-resolution optical microscope. A novel FEM-based iterative procedure is proposed, which enables an implicit evaluation of the material pair's coefficient of friction. CFRP gears exhibited a significantly improved performance in comparison with the plastic and composite gears.

3 - 4 pm - **Exhibitor Appreciation Break**

4 - 4:30 pm – **Gears Business Meeting**

4H 103C

Commercial Marketing Forum IV

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm - **Placeholder**

2:30 - 3 pm - **Evonik Oil Additives USA, Inc.**

3 - 4 pm - **Exhibitor Appreciation Break**

4I 104A

Electric Vehicles IV

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3834255: Oil Aeration: Findings for Testing in High Speed, Low Volume Systems
Ricardo Hein, Conexo Inc., Acworth, GA

Oil aeration is one of the key stressors for fluids in systems operating at high speed and with low volumes. An aeration tester was introduced t back in 2018 uses high agitation to secure a constant free air content in the fluid and it measures he aeration characteristics in fluids. A lot of effort has been dedicated to developing a valid and replicable aeration testing method. Recent development of this aeration testing system now allows for understanding the relations between aeration level in the fluids and the variables speed, volume, and temperature. The latest findings were performed to correlate to innovative mechanical designs such as are used in electrification. These findings include studies with variable temperature, with different volumes of fluid, and with different speeds. The testing apparatus and methods are described. This system opens the possibilities in testing the aeration characteristic of not just different fluids, engine oils, transmission and hydraulic fluids.

2:30 - 3 pm
3833698: Flammability and Combustibility of Oils in the Presence of High Voltages
Paul Shiller, FirstPower Group LLC, Twinsburg, OH

The electrification of vehicles adds an interaction that needs to be addressed. Having combustible and flammable materials in close proximity to high voltage is inherently dangerous. Not only for the materials used in the functioning of the vehicle but also other materials; cleaners, spray lubricants, and others used in the upkeep and maintenance of the vehicle. This presentation will discuss how flammability is measured and defined with respect to a flame and in the presence of an electrical spark. Both liquids and aerosols will be covered. High voltages sometimes lead to a condition of partial discharge. Partial discharge is where an electrical discharge does not completely bridge a gap. This can happen when

insulation is damaged or a conductive path develops. When partial discharge occurs and is submerged in oils it can lead to decomposition producing methane, hydrogen, acetylene, and other materials to track the health of the system.

3 - 4 pm – Exhibitor Appreciation Break

4 - 4:30 pm
3852434: Rheological Test Methods for E-Lubricants
Carlos Sanchez, Southwest Research Institute, San Antonio, TX

The move towards E-mobility presents new challenges in designing materials and lubricants to interact efficiently in a mechanical-electrical system. Lubricants in electric vehicles tend to behave differently in the presence of an electric field. There are many rheological test methods used for engine and drivetrain applications that are relevent to EV systems. Rheology can be used to evaluate lubricants for visco-elastic behavior, churning losses, and viscosity, to name a few. Previous studies at SwRI have demonstrated that an electric field affects the viscosity of new and used driveline fluids in different ways. Using a similar approach, other lubricant properties were investigated while subjected to an electric field. This work will discuss current rheological test methods used for evaluating greases and driveline fluids, and new methodologies being developed to meet the demands of electrification.

4:30 - 5 pm
3813679: Test Development for Copper Corrosion in E-fluids
Gwenaelle Philibert, Jiayi Liu, Shell, Houston, TX; Christopher Dobrowolski, Shell Global Solutions, Hamburg, Germany

The electrical windings in electric motors are predominantly manufactured from copper which provides impressive levels of electrical conductance, thermal conductivity and ductility at reasonable cost. Typically, the windings are electrically insulated using a thin coating of varnish and are vulnerable to electrical breakdown if the varnish degrades. As motor power densities have increased, the need for active cooling of the windings has risen, leading to the development of wet motors in which transmission lubricants are deliberately brought into contact with the windings to facilitate heat removal. Adverse interactions between the fluid and the varnish can precipitate electrical breakdown stimulating the development of protective oil performance specifications by many of the world's OEMs. Here, we report on the development of an analytical test capable of screening and comparing the copper corrosion performance of candidate lubricants.

5 - 5:30 pm
3831841: Monitoring of Electrode Degredation Within Lithium-ion Batteries During Prolonged Use
Daniel Williams, University of Sheffield, Sheffield, United Kingdom

The move to renewable energy sources requires the storage of said energy in order to meet current and future demands. The use of batteries as a storage method demands the increase in energy and power density, along with the longevity of the cells to reliably provide to our needs .Lithium-ion chemistries are the most prevalent battery technology, but are prone to degradation over time. A measurement system to monitor the degradation of the electrodes within lithium-ion cells non-destructively has been developed. Ultrasonic transducers were installed to the casing of a 2000mAh pouch Li-polymer cell. The transducers would emit ultrasonic pulses that would travel through the cell, recording information about the internal layers. As the battery degrades, the change in the signal response would be recorded and used to characterise the degradation. The variation in cell degradation over different charge rates will be explored.

5:30 - 6 pm
3833906: Efficiency and Range Determination Aspects for Fluid Development of Battery Electric Vehicles
Thomas Wellmann, FEV North America, Auburn Hills, MI

The use of innovative drivetrain technologies of fully electrified propulsion systems is expected to play an increasingly important role in helping OEMs meet the future fleet CO_2 reduction targets. One important aspect for battery electric vehicles is the driving range on a single battery charge. It is desirable to increase range by optimizing the driveline and overall vehicle efficiency without sacrificing comfort and performance. This presentation will showcase key drivetrain components, how their efficiency and performance can be evaluated via simulation and testing. Methods for fluid evaluations on component

level will be highlighted. Further, vehicle level testing for range determination will be described and details that can influence fluid selection will be highlighted. Examples from testing and simulation will be utilized to describe energy flow in various vehicle systems. The importance of fluids for lubrication and cooling on the overall vehicle energy management will be shared.

4K 201A

Metalworking Fluids IV

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3815325: Assessing the Functional Lubricity of MWFs by an Innovative Tool
Ameneh Schneider, Optimol Instruments, München, Germany

The compositions of MWFS must be developed constantly due to stringent occupational, health and environmental regulations, but without losing performance. Investigation on energy efficiency, coolant effect, lifetime of tools and finally the optimization of the concentration of active ingredients in the formulation are the subjects for more investigations. The innovative set up in SRV under unidirectional sliding helps to assess the functional and tribological performances of newly developed MWFs in a laboratory by using small amounts of fluid and test parameters based on various application field experiences. A large test matrix with different tool/work material combinations and fluid compositions was selected and performed. Optimization of test parameters for each material is necessary and will be discussed. The reproducible results of tribological performances (friction and wear) and temperature evolution during tests enabled a good ranking among the tested MWFs.

2:30 - 3 pm
3819234: Performance Testing of Sulfur-based Estolides in a Full Metalworking Fluid Formulation with Comparison of Other Commercialized Sulfur-based Additives.
Marlon Lutz, Biosynthetic Technologies, Indianapolis, IN

At Biosynthetic Technologies (BT), we aim to develop innovative high performing molecules in a sustainable fashion. Sulfur-based additives are one of the leading wear preventative additives to prolong machine life and performance. There has been a decline in the development of sulfur-based additives both conventional and bio-based, and with the movement to phase out chlorinated paraffins, this warrants the need to prepare and evaluate novel bio-based sulfur additives for the metalworking industry. BT has developed novel bio-based estolides with sulfur embedded and have successfully formulated into full water dilutable metalworking fluid formulations and evaluated anti-wear properties in comparison to other formulations that contained commercial sulfur-based additives. Performance testing of sulfur-based estolides will be discussed and these results show that sulfur-based estolides do deliver competitive anti-wear properties compared to commercially available sulfur-based additives.

3 - 4 pm - **Exhibitor Appreciation Break**

4 - 4:30 pm
3829851: Post Machining Cleaning – How to Pick the Right Surfactant for the Job
Stephanie Cole, Clariant Corporation, Mount Holly, NC

With the hundreds of available surfactants on the market to incorporate into a metal cleaning formulation, picking the correct surfactant can be daunting. Determining whether your formulation requires emulsification or rejection of foreign oil is critical for selecting the proper surfactant in a cleaning formulation. Understanding surfactant performance with various soil types, metal types, and pH stability will help the end-user achieve their desired cleanliness. The surfactant chemistry's backbone will determine the surfactant's functionality and application performance. This paper will define trends associated with different surfactant chemistries and how to apply this theory to developing a cleaning formulation.

4:30 - 5 pm
3833803: Synergy of Polymeric Esters in Synthetic Metal Forming Fluids
Andrew Yoder, The Lubrizol Corp, Wickliffe, OH

Polymeric esters have shown to provide excellent lubricity in synthetic metalworking fluids particularly stamping and drawing fluids. These esters have been shown to be equal to or better than traditional glycol-based or block copolymer-based lubricants without the inverse solubility associated with them. However, polymeric esters are not without their own drawbacks. This research will show that by combining two different esters, they provided better overall performance than each individually and matched or outperformed traditional polyglycol based chemistries. Data will also show a further synergistic effect when this combination is used with extreme pressure and/or anti-wear additives.

5 - 5:30 pm
3833542: Polyglykol as Performance Wear Lubricant and Synergism with EP Additives on Net Oil Metalworking Fluid (Part 2)
Eduardo Lima, Dow Chemical Brazil, Jundiai, Brazil

Effective additive development against wear is required in order to create more robust scientific information on earlier studies that takes into account known factors that affect wear, which brings negative aspects on the metalworking process, potential damages on metal parts, unwanted wear on relatively expensive tools, or inability to create adequate and precise measures on metal parts. It is possible to avoid the negative effects of metal-to-metal contact by incorporating the right chemicals that provide a barrier between surfaces, either through physical adsorption or even chemical reaction. This study presents performance results examining more from the Oil Soluble Polyglycol as Synthetic Performance Wear Lubricant Additive proposal and covering more on synergism with Typical EP Additives Study on Typical Net Oil Metalworking Fluid, creating relation between: additive molecular weight relation, bubbles release, and performance results.

5:30 - 6 pm
3830588: Next Generation Multi-Metal Wire Drawing Fluids
Kathleen Havelka, ANGUS Chemical Company, Buffalo Grove, IL

Vehicle electrification and growing energy consumption are driving demand for improved copper and aluminum wire drawing fluids. Wire drawing is a difficult operation requiring fluid formulations to provide several important characteristics. This presentation demonstrates the use of specialty amino alcohols in wire drawing fluids improve fluid performance and longevity, enabling formulators to develop high performing fluids with improved sustainability profile. In this study, wire drawing fluids developed using amino alcohols exhibit excellent lubricity, good cleanliness, and low foaming with extended fluid life. The structure-property relationships of the amino alcohols are explored highlighting unique functionalities formulators can leverage to develop fluids that produce defect-free wires, use less energy and generate less waste. These amino alcohols offer potential in developing next generation fluids that help lower total cost, reduce environmental impact, and increase productivity.

6 - 6:30 pm - **Metalworking Fluids Business Meeting**

4L 201B

Tribochemistry I

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3829853: Synergistic Effects of Anti-friction and Anti-wear Additives on the Tribological Behavior of Lubricants Derived From Plastic Wastes Under Boundary Lubrication
Pushkar Deshpande, Seungjoo Lee, Ali Erdemir, Texas A&M University, College Station, TX; Ryan Hackler, Massimiliano Delferro, Argonne National Laboratory, Lemont, IL; Yiyu Wang, Ranjan Behera, Wenyu Huang, Aaron Sadow, Iowa State University, Ames, IA

Plastic waste pollution is one of the most pressing issues around the world. Therefore, there is an urgent need for recycling or upcycling them for a green and circular economy. In this study, we investigate the tribological behavior of lubricating oils derived from upcycled plastics (LOUPs) with and without MoDTC and ZDDP in comparison to base oils. These LOUPs were previously studied as neat oils and they provided improved friction and wear properties. LOUP blends were prepared with specific concentrations of antiwear (ZDDP) anti-friction (MoDTC) additives. To investigate their synergistic effects, tribotests were performed under boundary lubrication. Results confirmed that these additives are fully compatible with LOUP and can provide significant friction and wear reduction. To understand the tribochemical mechanisms involved, we used analytical techniques such as Raman and X-ray Photoelectron Spectroscopies, that confirmed formation of highly protective and slick boundary films.

2:30 - 3 pm
3809257: Synergistic Interactions Between Bio-based Oleate Ester and Low-concentration ZDDP Under Reciprocating Contacts
Ju Shu, Cayetano Conesa, Mitjan Kalin, Ardian Morina, University of Leeds, Leeds, United Kingdom

To probe the potential of using bio-based materials as boundary lubricating additives for low SAPS lubricants, ethyl oleate, readily obtained from bio-based resource was investigated under reciprocating contacts in terms of tribological performance. Several surface analysing techniques including SEM , AFM, synchrotron XAS and ToF-SIMS were then utilized to study the worn surface. A synergy on tribological performance has been observed when the ethyl oleate has been used together with low concentrations of ZDDP showing both lower friction and wear loss, compared to only ethyl oleate or ZDDP as additive with the same total concentration. Based on analyses, we propose a mechanism where ZDDP provides essential resource to the tribo-film composed of glassy zinc polyphosphate to mitigate wear loss and ethyl oleate alleviates shear strength to facilitate the formation of zinc polyphosphate and homogenises tribo-film distribution.

3 - 4 pm – Exhibitor Appreciation Break

4 - 4:30 pm
3833824: Mechanochemistry Study of ZDDP Antiwear Additives
Lu Fang, Robert Carpick, Martin Webster, University of Pennsylvania, Philadelphia, PA; Spyridon Korres, ExxonMobil, Hamburg, Germany

Recent experiments in the elastohydrodynamic lubrication regime revealed zinc dialkyldithiophosphate tribofilm is driven via shear stress. However, those experiments neglect the inhomogeneous stress distribution. We present a new approach, Contact Strip Analysis Method (CSAM), accounts for and takes advantage of the stress variation. In CSAM, the contact is discretized into multiple strip-shaped sub-areas for kinetic analysis. Compared to current methods, CSAM provides better spatial precision, and more efficiency to study mechanochemistry with fewer experiments. The data followed stress-assisted thermal activation (SATA), permitting measurement of activation energies and volumes for tribofilm growth. We also used atomic force microscope to investigate tribofilm growth in the boundary regime. Three growth stages were observed: slow linear growth, fast linear growth, and then fast removal. The first two follow SATA. The mechanisms behind the multiple growth stages will be discussed.

4:30 - 5 pm
3830539: Influence of the Organic Moiety on the Tribological Properties of MoS_2: Glycol Hybrid Nanoparticles Based Dispersions
Fabrice Dassenoy, Jules Galipaud, LTDS/ECL, Ecully, France; Inaki Garcia, Ivet Kosta, Hans Grande, Eva Garcia-Lecina, CIDETEC, San Sebastian, Spain

MoS_2: glycol hybrid nanoparticles were synthetized through a polyol route. Their tribological properties when used as lubricant additives in a PAO6 base oil were investigated using a pin-on-disk tribometer. An important friction reduction and good anti-wear performances were observed compared to the base oil and to the no modified particles. The post mortem characterization showed that the tribofilm formed on the wear surfaces during the friction test is at the origin of the excellent tribological performance of the MoS_2 nanoparticles. In particular, it was demonstrated that the interaction of MoS_2 with the organic moiety of the nanoparticles plays a key role in the friction reduction and the good anti-wear properties of the dispersions.

5 - 5:30 pm
3811302: The Influence of Slide–Roll Ratio on Glycerol Oleate Tribofilm Formation in the Boundary Lubrication Regime
Marjan Homayoonfard, University of Leeds, Leeds, United Kingdom

Ever tightening environmental and emissions legislation creates demand for lubricant additives with low or no phosphorus and sulphur contents. Many organic friction modifiers fulfil these requirements. However,the mechanisms by which they lower friction and protect surfaces in the boundary lubrication regime are still not fully understood. We have performed tribological studies with steel surfaces of the three glycerol oleate OFMs (including combinations of them).Formulations of glycerol monooleate (GMO), glycerol dioleate and glycerol trioleate in PAO4 base oil were tested at two different temperatures in an MTM-SLIM tribometer as a function of sliding-rolling ratio (SRR),from pure sliding to pure rolling conditions. The thickness of the formed tribofilms was tracked throughout the experiments and their chemical composition was subsequently examined using ToF-SIMS. The correlation between the tribofilm formed, running conditions and the tribological performance will be discussed in detail.

5:30 - 6 pm
3812998: In-situ Carbon Tribofilm Formation Given by a Novel Organic Friction Modifier
Wei Song, Jinjin Li, Jianbin Luo, Tsinghua University, Beijing, China

Organic friction modifier (OFM) can effectively reduce friction coefficient, especially during boundary lubrication. Usually, the tribological performance of an OFM depends on the interfacial interaction between the tribopair surface and OFM. In this work, a novel OFM without sulfur and phosphorus was synthesized and employed as an additive in PAO. This OFM provides a much lower friction coefficient and wear track width than reported amphiphilic friction modifiers, like oleic acid. Surface analysis including AFM, Raman, FTIR, XPS and TOF-SIMS show that there is a 30~50 nm viscoelastic tribofilm formation on the wear track, and it is mainly composed of graphite carbon. This work reveals a fundamental understanding of OFM mechanism and might guide the novel OFM development.

4N 202B

Nanotribology IV

Session Chair: Diana Berman, University of North Texas, Denton, TX
Session Vice Chair: TBD

2 - 3 pm - **Invited Talk**
Astrid de Wijn, Professor, Norwegian University of Science and Technology

3 - 4 pm - **Exhibitor Appreciation Break**

4 - 5 pm
3852275: Invited Talk: Molecular Friction Studied by Stereographic Force Spectroscopy
Bizan Balzer, University of Freiburg, Freiburg, Germany

Little is known about how the directionality of an applied force affects the friction behavior at the molecular scale. Atomic force microscopy (AFM) based stereographic force spectroscopy is ideally suited to study the adhesion and friction of single polymers and single bonds under liquid conditions using a combination of vertical and lateral pulling (i.e., angle-dependent pulling).[1] Here, the directionality of bonds and their influence on adhesion and friction is investigated for covalent bonds, coordination bonds, π-π stacking and receptor-ligand-protein complexes.[2,3] These findings are crucial to understand interfacial interactions for a the bottom-up development of materials with optimized friction properties.
References
1. Balzer, B. N. et al. (2013). Angew. Chem. Int. Ed., 52(25), 6541.
2. Cai, W. et al. (2022). Chem. Sci., 13(19), 5734.
3. Cai, W. et al. (2022), Anisotropy of π-π Stacking as Basis for Superlubricity, ACS Mater. Lett., accepted.

5 - 6 pm - **Nanotribology Business Meeting**